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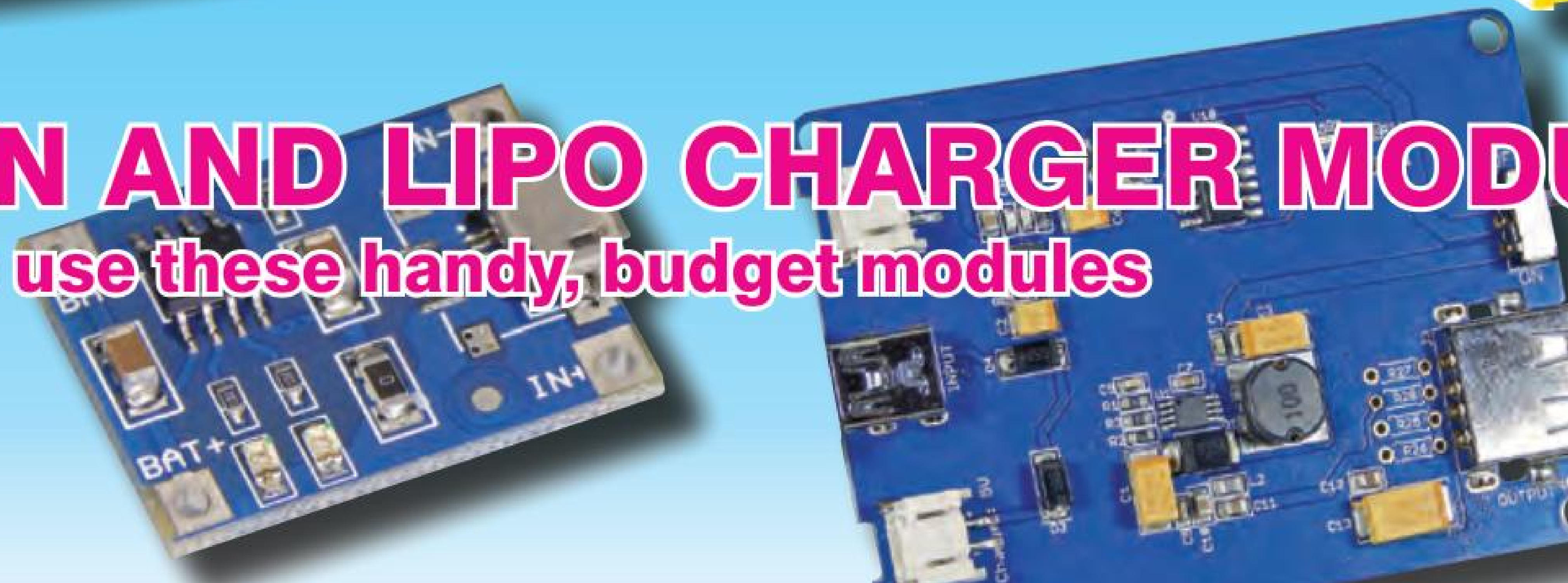

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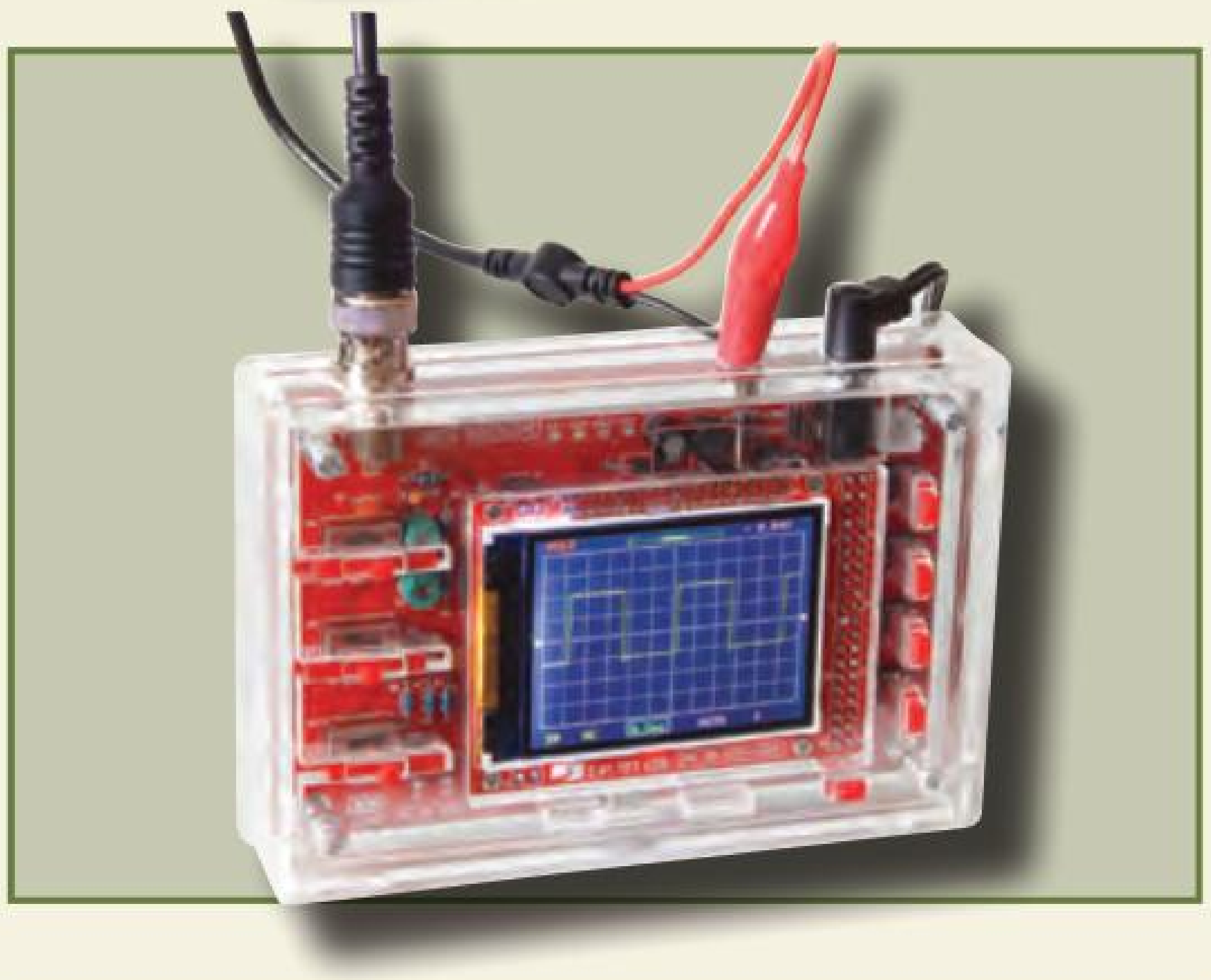

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EPE EVERYDAY PRACTICAL ELECTRONICS

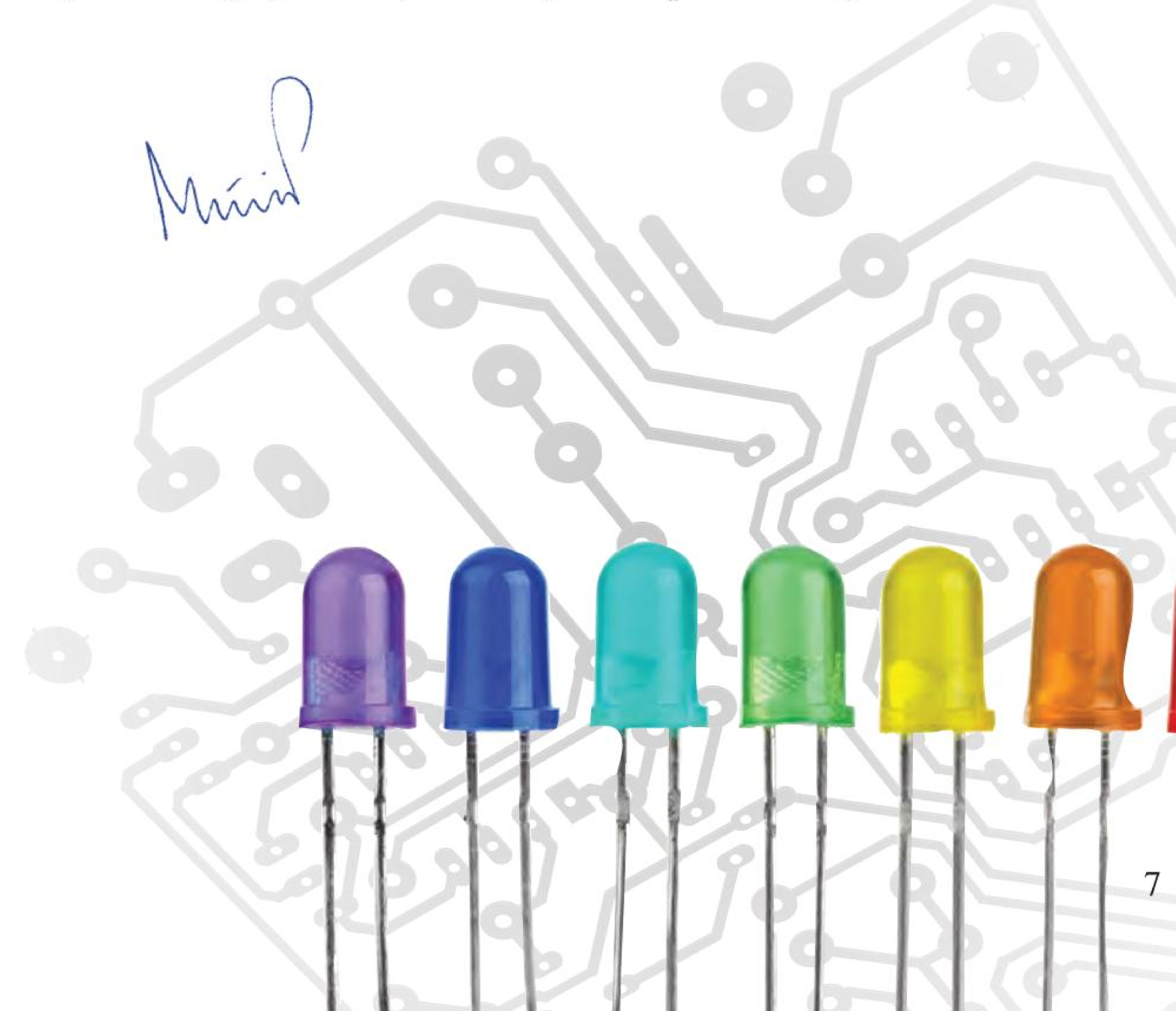
It's an analogue world

It's a pretty astonishing idea – for those of us of a certain age – there are now adults who were born *after* the widespread introduction of the Internet. For this always-connected, always-on generation, the world looks very digital. From music, film, books and newspapers, to photography, radio, TV, tax returns and maps… the great digital march seems endless, unstoppable and entirely normal.

(Almost) none of this existed when I went to university in the early 80s – in fact, the Compact Disc was launched the month before I landed at my first lecture, but they were very pricey and everywhere you looked buying and playing music meant vinyl records or cassette tapes. True, personal computers were starting to make a real impact on basic office functions or gaming, but digital literacy was still confined to relatively small, dedicated groups of enthusiasts. For most people, day-to-day existence was a decidedly analogue experience.

To contemporary young eyes, the extraordinary advantages that modern digital technology offers must make the pre-digital era look like another planet – but it is worth remembering that the pre-digital era was *not* the Stone Age. Technological solutions from those days can still be fascinating and entirely relevant.

So, where is this slightly random musing leading to? This month, we start a series of articles by Jake Rothman – our resident *Audio Out* columnist – on analogue synthesis and synthesisers. 'But surely this is retro technology that belongs in a museum?', I hear you cry! Well, no … and no! First, analogue synthesisers really can make music that is very difficult to replicate digitally, and that in itself is enough of a reason to build them. Second, it is important to remember that the real world is analogue, not digital. Every digital electronic circuit is really an analogue circuit driven to certain extremes. If you really want to understand how to design digital projects then analogue electronics should be your first port of call. I think you will find the analogue circuits Jake discusses over the next few months are absolutely fascinating and relevant to all modern designers and hobbyists – I urge you to try building and experimenting with them.



NEWS

A roundup of the latest Everyday News from the world of electronics

Digital Television Group Summit 2018 – report by Barry Fox

The Annual Summit of the UK's Digital Television Group (DTG), held recently in London at the Royal Society of Medicine in Wimpole Street under the title 'Transforming TV', curiously had no sessions devoted to 4K UHD or 8K – even though Sharp has already promised 8K sets for the UK and Europe, to challenge 4K UHD. But the Summit did provide some industry insight into what 5G wireless will offer over 4G, other than higher data speeds.

5G slicing vs 4G

Said Matt Stagg, Director of Mobile Strategy, BT Sport, who was previously with mobile operator EE: '5G is not just a faster version of 4G with low latency (responses to data queries sent over a 5G wireless link can be received back within one millisecond).'

'Low latency only happened because the automotive industry needs it for braking autonomous cars' he said,' so that cars stop at a red light'.

'If it hadn't been for the auto industry, latency would have been 10ms', he said before warning that 'low latency is expensive to provide from the network equipment.'

'But not everyone needs it', he went on. 'VOD, DTT, cameras, vehicles – all have different requirements. So the big difference between 4G and 5G is that whereas with 4G everyone gets the same, 5G lets the operator slice the network into virtual networks which offer different configurations, some with low latency, some not. With virtual networks, outside broadcast cameras at events like glastonbury aren't competing for bandwidth with other users with different requirements.'

Simon Fell, former director of technology & innovation at the EBU, backed up Stagg's scenario of networks collapsing when all users, consumers and professionals alike, are sharing the same pot of data and something happens to increase demand dramatically.

'4G does not work under extreme load' Fell said. 'I was in Munich when there was a series of attacks and as more and more people used their phones to access sites like Facebook, the network collapsed. News crews with 4G cameras could not communicate and they had to bring in a satellite truck'.

With 'sliced' 5G, he said, the broadcasters would have not been affected by the consumer overload because they would not be competing for bandwidth.

8K on 5G?

When asked whether using 5G might perhaps be the way to distribute data-hungry 8K broadcasts, which cannot easily be carried by DTTV or even satellite channels, Matt Stagg went off at a tangent, reminding that small screen mobiles don't need 4K content, let alone 8K. Guido Mardi, CEO of V-Nova, the British company that promotes the new Perseus IPTV compression codec, jumped in to promote Perseus. Tests conducted by V-Nova, he said, showed that it was already possible to reduce an 8K data stream of 50Mbps to between 30 and 35Mbps, which could easily be sent over a 5G link.

Simon Fell added that NHK was already experimenting with 8K over 5G. 'But who will pay?' he wondered.

A politician's view

The Summit ended with a colourful address, with a Q&A session, by Ed Vaizey, the Conservative MP who served from 2010 to 2016 as the UK's Minister for Culture, Communications and Creative Industries under Prime Minister David Cameron, and was widely regarded as a 'friend of the broadcast industry' before leaving when Theresa May took over the government from David Cameron.

I did not 'stand down' Vaizey said. 'I was sacked. – It was on 14 July 2016 at 5.37pm' he added with a broad grin, 'But I'm not bitter'.

Vaizey then recounted how the fateful call from Theresa May had been delayed by 20 minutes because 'I, who was the Minister responsible for ensuring that everyone in the UK gets a good mobile signal, was driving near the River Thames and my phone lost signal just when the Prime Minister was trying to call me. So I was sacked 20 minutes late'.

Noting in passing that, 'I remain sceptical about the benefits of VR for the consumer', Vaizey then revealed that 'the previous Chancellor of the Exchequer George Osborne thought outside the box and was in favour of switching the

Digital Television Group Summit 2018 – *continued*

UK to IPTV. But he left with David Cameron. Now the IPTV debate is not really happening. It's not being talked about in mainstream political circles. But it may emerge as spectrum becomes scarce.'

'The other issue we need to look at in the UK is the dominance of the US tech giants in the digital landscape. The tech sector always says that politicians don't understand technology. My answer to that is that it's not a politician's role to understand technology; it's a politician's role to reflect the concerns of civic society and to challenge the tech companies. It was inevitable when Mark Zuckerberg appeared before the Senate that the outcome of that would be mocking criticism of the Senators for not understanding Facebook's business model. That may have been justified criticism, but the fundamental point is that there is a lot of content on these platforms that shouldn't be there.'

Bombes away!

On the 23 June 2018 (the 106th anniversary of Alan Turing's birth), the new Bombe Gallery in The National Museum of Computing (TNMOC) was opened by two of the original bombe operators.

The bombe was an electro-mechanical device used by British cryptologists to help decipher German Enigma-machine-encrypted secret messages during the Second World War. The initial design of the bombe was produced in 1939 at the UK Government Code and Cypher School (GC&CS) at Bletchley Park by Alan Turing.

It was designed to discover some of the daily settings of the Enigma machines on the various German military networks: specifically, the set of rotors in use and their positions in the machine; the rotor core start positions for the message and one of the wirings of the plugboard.

Thanks to the generosity of Crowdfunder donors, who raised more than £50,000 in March, the arrival of the TNMOC's new bombe was accomplished smoothly and quickly.

Visitors to the museum will be able to see the bombe reconstruction in action and learn how it broke enemy Enigma messages in the Second World War – and compare it to the acclaimed working Colossus, a valve-based computer reconstruction, and discover how it was instrumental in breaking Lorenz messages.

New virtual reconstructions of the wartime code-breaking, as created by a TNMOC volunteer on a PC, will also be on display.

The new exhibit will give visitors extra insight into how wartime ingenuity kick-started British post-war computer developments that led directly to today's digital world.

Up and running – the new Bombe at TNMOC

Beam me up!

In the TV and film franchise *Star Trek*, one of the key technologies driving multiple story lines is teleportation – invariably accompanied by the catchphrase, 'Beam me up!'. It is of course fantasy, but like much well-written science fiction it spurs real scientists to investigate if any aspect of the idea is feasible.

One simple question is how much time is required to send the data needed to teleport a human being? Four University of Leicester physics students have calculated the answer to this very question in their paper, *Travelling by Teleportation*, published in the latest volume of the University of Leicester's *Journal of Physics Special Topics*.

The students investigated the teleportation of a human being from a location on the Earth's surface to a space in circular orbit directly above it. To begin the teleportation process, every human that is teleported will need to be represented in transferable data. At a basic level, the transferable data of a human would be represented by the DNA pairs that make up genomes (which contain the entirety of an organism's hereditary information) in each cell.

The total data for each human cell was calculated as approximately 10^{10} bits, and one cell contains enough information to replicate any other type of cell in the body.

Mentally rebuilding a person is not so simple. The full information of the traveller's brain is required, which brings the total information content up to around 2.6×10^{42} bits.

Unfortunately, assuming the bandwidth used is 30GHz, the students discovered that the data transfer would require up to $4.85 \text{x} 10^{15}$ years – around 350,000 times longer than the age of the universe.

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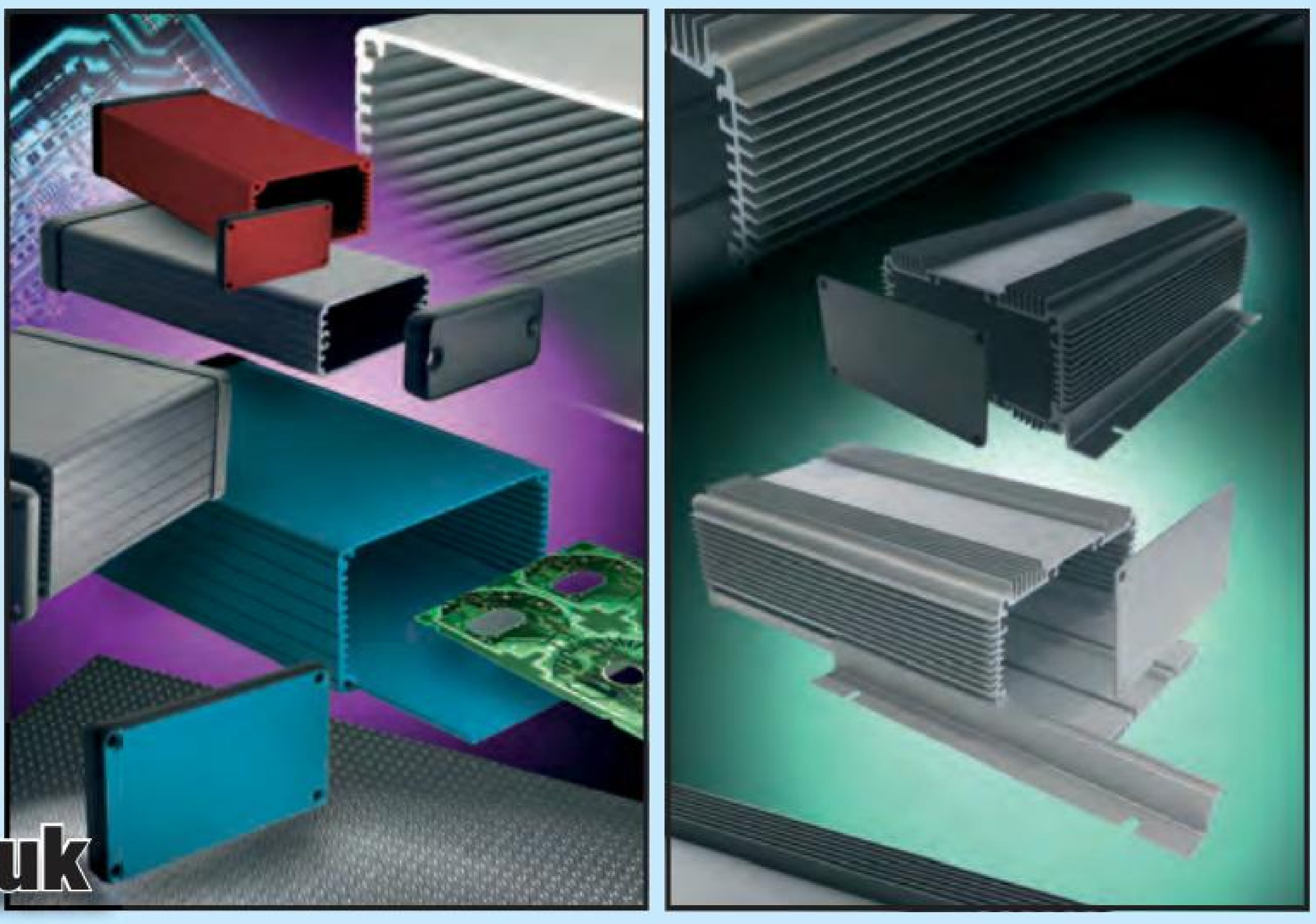

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TechnoTalk

Two eyes good, more eyes better

Mark Nelson

Would being able to see clearly in fog or snow make you a better car driver? Stupid question; of course it would. Right now, only 'Marilyn' can do this, but there's a practical electronic solution called 'lidar' that might assist all motorists in the near future.

OK, YOU ASK, WHO IS THIS Marilyn? Well, Marilyn is not a human but an automated car developed in Finland by VTT, the premier technical research and technology organisation in the Nordic countries. And as smart cars go, she is one of the smartest, able to follow pre-programmed routes and avoid collisions without input from a driver. Marilyn can see far better than any human driver can and drives safely through the kind of fog and falling snow that would keep mere humans off the roads altogether.

And the relevance is?

If you're like me, and don't trust autonomous or driverless cars, even if they are able to spot humans in thick fog and avoid accidents automatically, it's highly likely that the technology that makes all this possible will still reach you, as it trickles down to become an option for conventional road vehicles, making us all safer on the road. In any case, the electronics are fascinating and you wouldn't be reading this article if you weren't interested in fascinating – and practical – electronics.

And practical it is, because similar techniques are already in everyday use (but I'll come back to that later). But what makes Marilyn so sharp-eyed? Is it a new kind of radar? Almost. In fact, it's 'lidar', which stands for 'light detection and ranging'. Lidar is entirely comparable to radar, but employs light waves instead of the radio waves used in radar. Sometimes called 'laser scanning' or '3D scanning', lidar measures the distance to a target by illuminating the object with pulsed laser light and measuring the reflected pulses with a sensor. Analysing the differences in laser return times and wavelengths is then used to create 3D representations of the target. You can read more on the subject and see some fabulous images on Wikipedia: **https://en.wikipedia.org/wiki/lidar**

VTT's robot car (Marilyn) has lidar equipment mounted on the vehicle's roof, exploiting new 1,550nm-wavelength technology combined with additional software intelligence, which improves its sensor's capabilities. Lidar scans – 'sees' – in the visible and near-infrared ranges of the spectrum, enabling the robot car to better identify humans and animals. Dedicated software modules have been included for the filtering of 'point clouds' (sets of data points produced by 3D scanners) and the assessment of scanner reliability, which ensure the vehicle can even function in fog and powdery snow.

Best of both worlds

'Although Marilyn's vision is limited to roughly 30m in thick fog, the new type of lidar does allow the car to be driven slowly rather than having to fully stop,' says project manager Matti Kutila of VTT's RobotCar crew team. Marilyn is also equipped with traditional automotive radar and older 905nm forms of lidar, but that technology's detection of non-metallic obstacles and resolution is limited, particularly when trying to recognise shapes.

'The old 905nm lidars cannot see through mist, whereas the new 1,550nm lidar is the only sensor on which a decision to swerve can be reliably made. Marilyn combines radar and lidar technologies by optimising the best aspects of the different sensors. This makes the automatic vehicle safer than a car driven by a person, and although there are still a lot of issues in the development path, a major leap has been taken in the right direction,' he asserts.

This summer, Marilyn's agenda is testing her skills in an automated parking exercise, following commands given from outside the car. We mustn't forget her husband either, a driverless car called 'Martti'. His next task is learning to make route selections based on friction data and lidar.

Unseen sentinel for safety

Lidar may figure low down the scale in public perception, but it already plays a vital traffic safety role in Britain and elsewhere. You may well have driven past a lidar installation recently, totally oblivious to its presence. That's because lidar is now used (in conjunction with radar) for obstacle detection at railway level crossings. 'Obstacles' include pedestrians walking across the tracks, vehicles that have the misfortune to run out of fuel or break down on the railway, plus animals and all manner of foreign objects that may be causing an obstruction.

The radar and lidar perform two different functions. Radar is the safety-critical component and is required to detect objects in the surveillance area that would be a danger, such as vehicles, people or large animals. Radio signals operating on millimetre wavelengths detect when their beam is interrupted. The transmitting antenna emits a beam signal to a transceiver, and when an object enters the path of the beam, this weakens the received signal, indicating intrusion. By using reflectors and amplifiers, a closely woven array of beams can be created across an area. So, a beam could be placed across each entrance and diagonally from corner to corner to protect the crossing.

Perfect combination

However, because radar is unable to detect obstacles lower than twenty inches (500mm) above the road surface, lidar is used to detect objects such as small children and prone bodies in the space below the area covered by radar. Light uses shorter wavelengths than radio waves, meaning that lidar offers the potential for greater accuracy than radar. The crossing area is scanned with pulses of near-infrared light that are reflected off the surface of any object in range. The reflected pulses are then analysed to determine a target's location, direction and speed.

The twin combination of radar and lidar is ideal. An advantage of radar over other means of detection is that some safe low-density objects, such as empty cardboard boxes or paper bags, will be ignored. On the other hand, the superior sensitivity of lidar can make it susceptible to small-sized objects, such as water vapour droplets that make up fog (which can be mitigated by software algorithms).

Universal Temperature Alarm

By JOHN CLARKE

9V 50mA
+ –
Temperature
Under
Sensor input
Universal Temperature Alarm

Features

- Small size
- Over-temperature indication
- Under-temperature indication
- Over and under-temperature alarm
- Adjustable upper and lower-temperature thresholds
- Easy calibration
- Selectable over and under-temperature alarm options

This compact alarm can be used to monitor the operating temperature of a whole range of devices. You could use it to monitor your tropical fish tank, your home brew, freezer, fridge, hot water system or whatever. It can monitor temperatures over the range –33° to 125° Celsius and provides an alarm when the temperature is above, below or not within a specified temperature range.

This project was originally developed with the specific intention of monitoring a tropical fish tank and to replace an earlier aquarium temperature alarm – hence, the 'fishy' front panel in the photo above.

The PCB for that project is no longer available and so we decided to revise it and also provide an on-board piezo transducer as the audible alarm.

Having done that, it was quite obvious that the project has much wider applications and so we are presenting it as a *Universal Temperature Alarm*.

Harking back to the original application, if you're using it to monitor a tropical fish tank, you would normally set the upper temperature limit at 26°C and the lower limit at 24°C – quite a narrow band of temperatures to keep your fish happy and well.

If the temperature drifts outside this range, the piezo transducer will sound and one of the warning LEDs will light – red for hot, blue for cool.

On the other hand, for universal monitoring applications, you can set the upper temperature limit as high as 125°C or as low as –33°C; boiling or deep frozen; probably not all that good for fish (unless they're scaled, cleaned and waiting in the freezer... and the *Universal Temperature Alarm* can be used to monitor that as well!).

The unit is housed in a plastic case and is powered using a 9V or 12V DC plugpack, or 12V battery. A handmade temperature probe connects to the alarm using a 3.5mm jack plug.

Circuit description

The circuit of Fig.1 employs six op amps and an LM335Z temperature sensor. While it may look complicated, only two op amp IC packages are involved and you can put it together easily in an hour or so.

Best of all, for those readers who find soldering small components a challenge, no surface-mount components are used. (Do we hear clapping and a loud cheer?)

The six op amps are contained within an LMC6484AIN quad op amp package and an LMC6482AIN dual op amp. Both devices are rail-to-rail, which means than their inputs and outputs can swing over the full supply voltage range, which in this case is 5V.

Three of the op amps (IC1a, IC1b and IC1c) are used as unity-gain buffers and another (IC1d) as an oscillator for the alarm. Two op amps (IC2a and IC2b) make up a window comparator that is the heart of the circuit.

Temperature sensing is performed by an LM335Z, fed with current via a

2kΩ resistor from the 5V supply. It produces an output voltage that is directly proportional to temperature in kelvin.

Kelvin is the temperature scale that begins at absolute zero (the coldest temperature possible), equal to –273.15°C. Also note that it is never expressed as 'degrees kelvin' or '°K' – it is simply 'K' (always upper case, but spelt out as 'kelvin', lower case).

The sensor output is typically 10mV/K, with the theoretical output at 0V at 0K. At 0°C (273K) the output voltage is typically about 2.73V.

The sensor's output is filtered with a 100nF capacitor to remove any noise that could be picked up in the sensor leads. IC1a then buffers the sensor voltage so it provides a low impedance feed to the window comparator inputs of IC2a and IC2b.

Window comparator

What is a 'window' comparator? Answer: it is pair of comparators which work together to sense whether a voltage is above a set limit (the upper comparator) or below another set limit (the lower comparator).

In our circuit, IC2a is the upper comparator and IC2b is the lower comparator. The buffered sensor voltage is applied to inverting input pin 2 of IC2a and non-inverting input pin 5 of IC2b.

Each of these op amps needs a reference voltage which is then compared with the buffered sensor voltage.

So we need two reference voltages, one for each comparator. IC1c buffers the voltage from the upper threshold trimpot VR1, which is connected between a 6.8kΩ resistor from the 5V supply and a 16kΩ resistor to the 0V supply. The resistors restrict VR1's wiper range to between about 2.4V and 3.96V. The maximum voltage corresponds to 123°C, while the lower voltage corresponds to –33°C.

Note that the LM335Z we used is only suitable for use up to 100°C. However, this wider range is included so that the alternative LM235Z, rated for up to 125°C, could be used if you wanted the extra range.

The connection for the lower threshold trimpot VR2 is a little more complex.

Op amp IC1b buffers the voltage from the low side of VR1 and its output connects to the lower side of VR2, while its upper side connects to the output of IC1c (ie, the buffered VR1 output).

So VR2 provides the lower threshold adjustment which will always be below (or equal to) the upper threshold voltage.

We have set up the circuit so that the lower threshold voltage can never be above the upper threshold voltage,

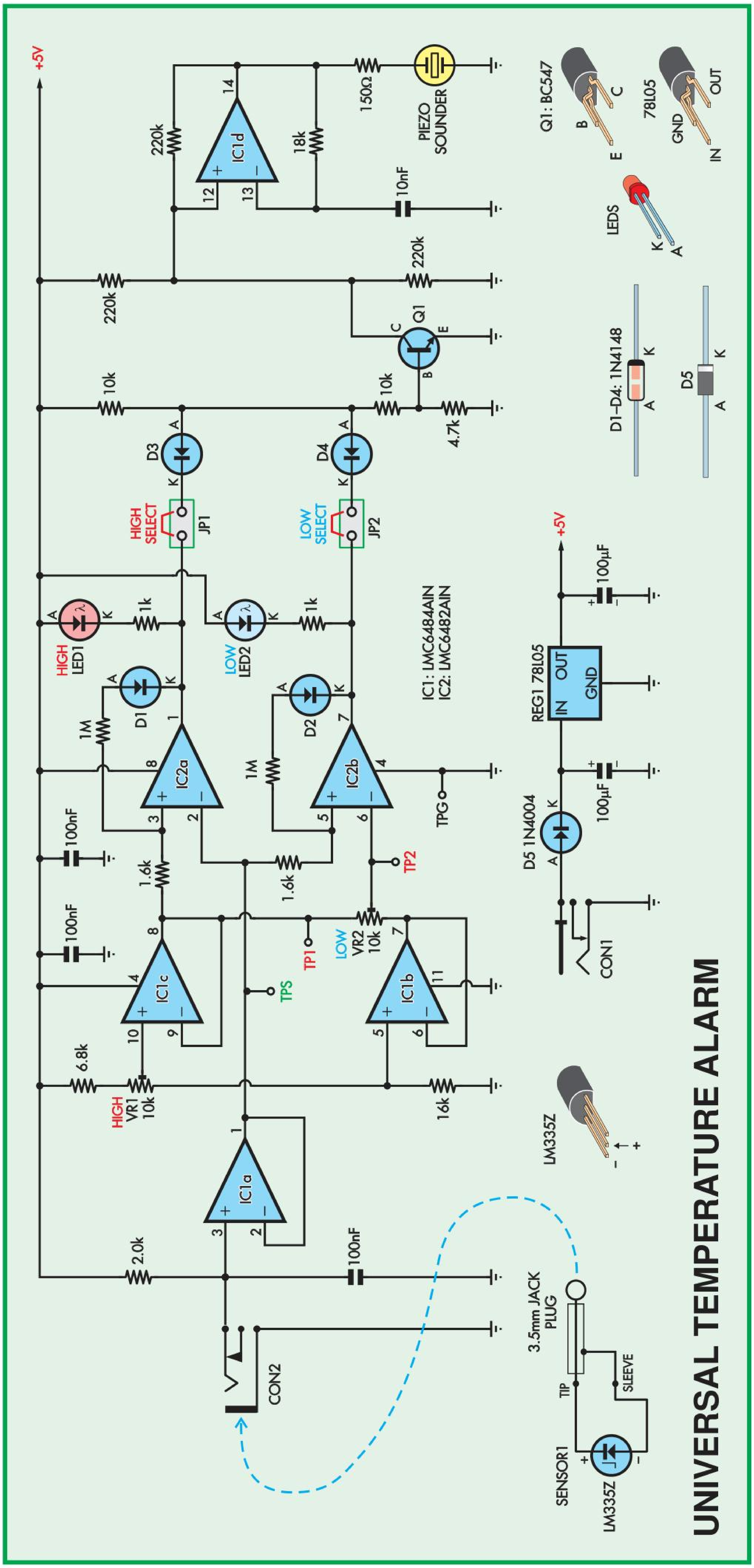

UNIVERSAL TEMPERATURE ALARM
+5V
220k
14
IC1d
12
13
18k
150Ω
PIEZO SOUNDER
10nF
220k
220k
Q1
C
B
E
10k
10k
4.7k
D3
D4
A
K
HIGH SELECT
JP1
LOW SELECT
JP2
HIGH LED1
LOW LED2
λ
1k
1k
D1
D2
1M
1M
IC2a
IC2b
8
1
2
3
4
5
6
7
TPG
TP2
TP1
TPS
100nF
100nF
1.6k
1.6k
IC1c
IC1b
9
10
11
LOW VR2 10k
HIGH VR1 10k
6.8k
16k
IC1a
2.0k
100nF
CON2
CON1
IC1: LMC6484AIN
IC2: LMC6482AIN
REG1 78L05
IN
OUT
GND
100µF
100µF
D5 1N4004
Q1: BC547
78L05
LEDS
D1–D4: 1N4148
D5
LM335Z
3.5mm JACK PLUG
TIP
SLEEVE
SENSOR1
LM335Z

Fig.1: the circuit is based on a window comparator comprising op amps IC2a and IC2b with upper and lower thresholds set by trimpots VR1 and VR2. If the temperature sensor voltage is above or below the limits set by VR1 and VR2, the outputs of IC2a or IC2b will forward bias diodes D3 or D4 respectively, and Q1 will be turned off to allow the oscillator based on IC1d to drive the piezo transducer.

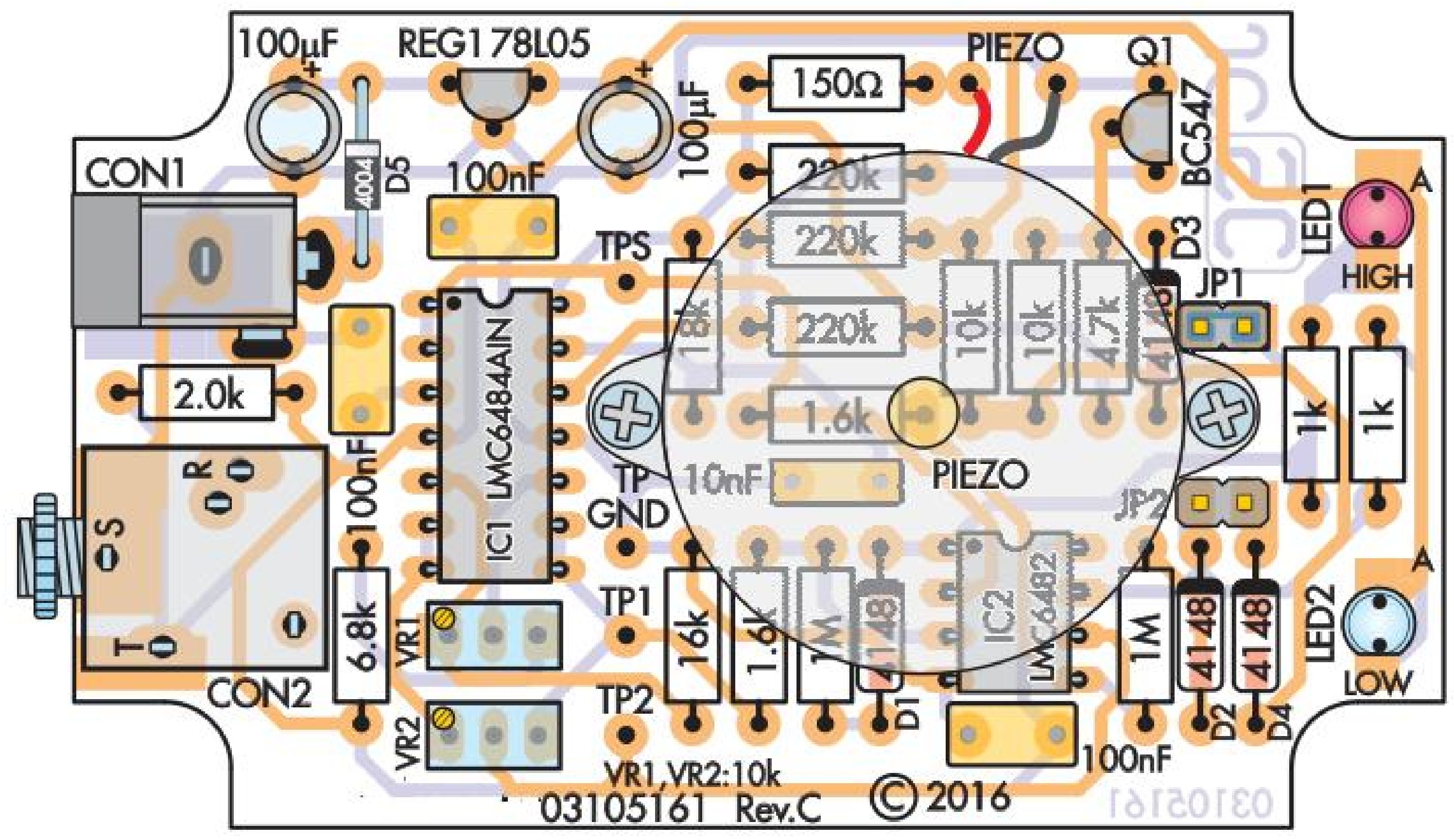
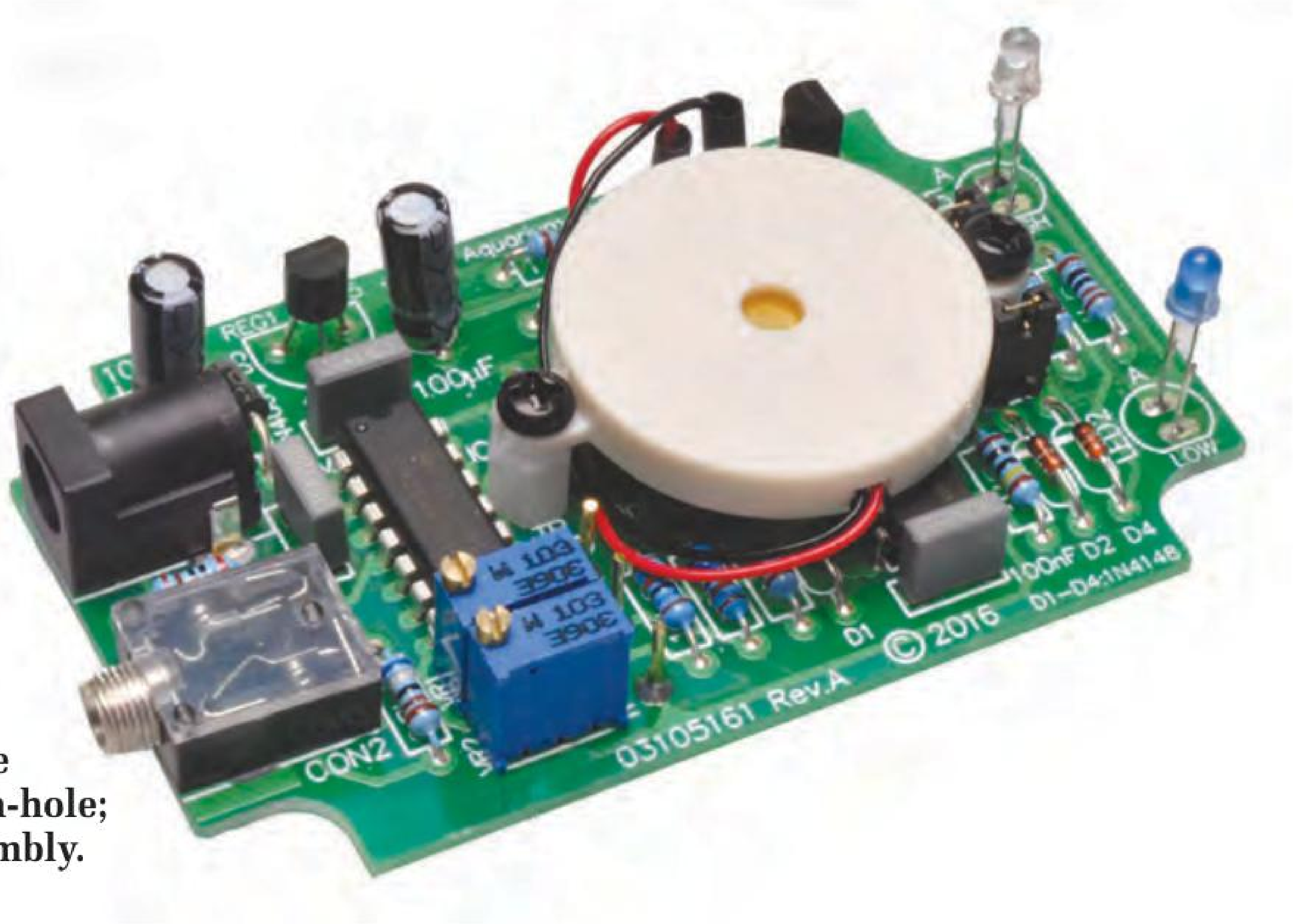


Fig.2: assemble all the small components onto the PCB before you mount the piezo transducer. All components are through-hole; no surface-mount components have been used, for easy assembly.



because otherwise the window comparator would not operate correctly.

Both the window comparator outputs are high (ie, +5V) when the sensor voltage is between the upper and lower threshold voltage. This is the normal condition for which the alarm does not sound.

In this condition, diodes D3 and D4 are reversed biased when the op amp outputs are high (ie, when links JP1 and JP2 are connected).

So consider what happens when the monitored temperature goes above or below the specified range.

IC2a's output will go low (0V) when the sensor voltage goes above the threshold voltage set by VR1. Similarly, IC2b's output will go low when the sensor voltage goes below the threshold voltage set by VR2. In the former case, D3 is forward biased and in the latter case, D4 is forward biased.

In each case, transistor Q1's base voltage will be pulled down and it will switch off, enabling the alarm signal provided by op amp IC1d to drive the piezo transducer.

IC1d is connected as a Schmitt trigger oscillator, with its non-inverting input (pin 12) connected to three 220kΩ resistors. One resistor connects to the +5V supply, the second to 0V and the third to the op amp output.

The inverting input is connected to a 10nF capacitor that goes to 0V and to an 18kΩ resistor that connects to the op amp output. The 220kΩ resistors set the input bias and the hysteresis for the Schmitt trigger oscillator. (We'll come back to that point in just a moment.)

When power is applied, the 10nF capacitor at the inverting input (pin 13) is discharged, and therefore the inverting input is low and the output at pin 14 will be high. The 10nF capacitor then commences to charge via the 18kΩ resistor to just over 3.33V, which is the lower threshold set by the 220kΩ resistors.

At that point, the circuit toggles so that the output at pin 14 goes low and the 10nF capacitor discharges towards the lower threshold of 1.66V.

This cycle repeats whenever Q1 is off and the result is a square wave of approximately 3.5kHz at the output of IC1d (pin 14). This drives the piezo transducer.

Window comparator hysteresis

Both the comparators based on IC2a and IC2b incorporate a small amount of hysteresis, as mentioned above. This prevents the op amps from oscillating on and off at their respective threshold voltages.

For IC2a, the 1MΩ resistor and diode D1 pull the non-inverting input slightly lower when IC2a's output goes low, by about 4mV. The 1.6kΩ resistor to IC1c's output sets this voltage change.

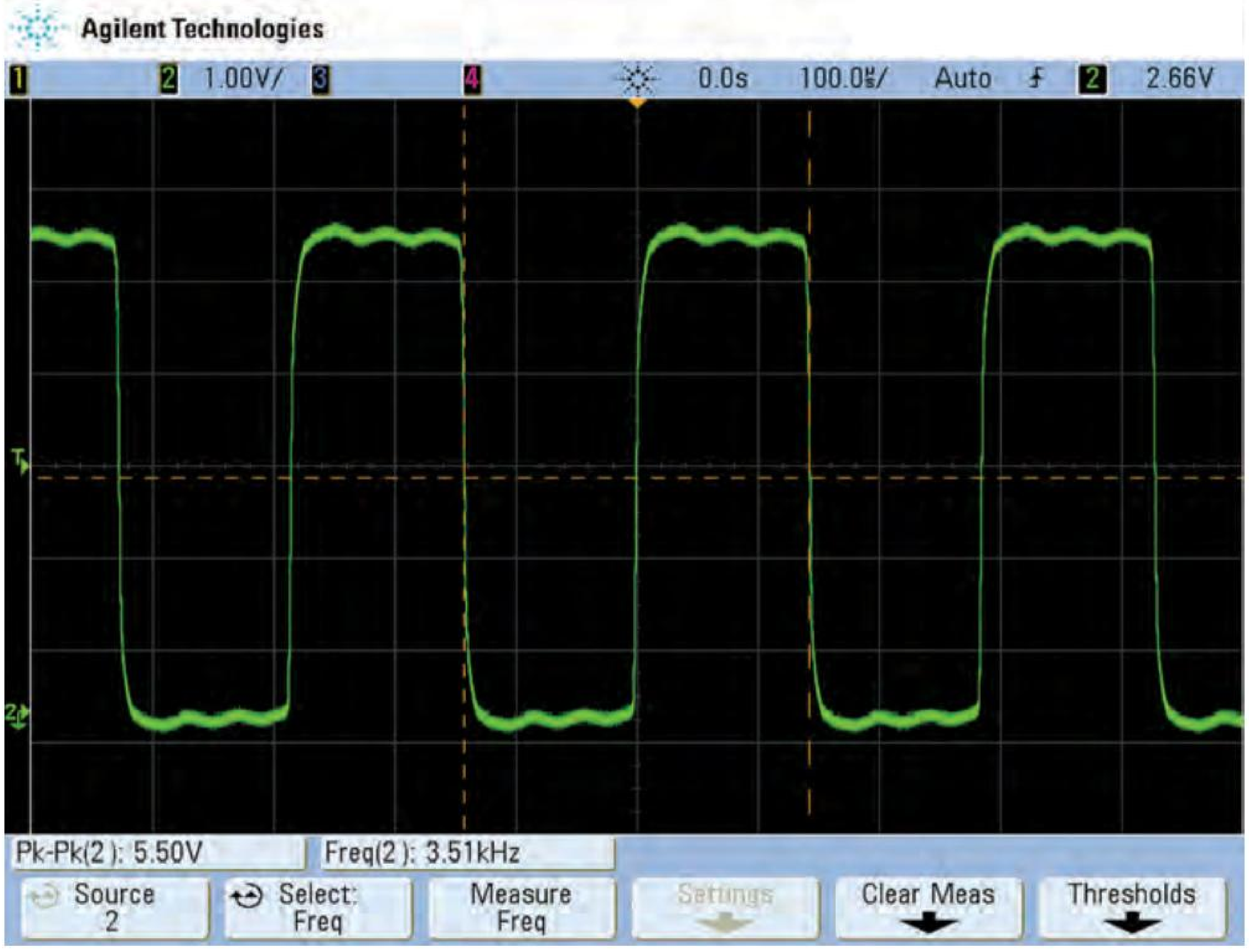
This effectively shifts the upper threshold voltage detected by IC2a lower by 4mV. So the sensor voltage needs to drop by a further 4mV before the IC2a output will go high again.

For IC2b, the 1MΩ resistor and diode D2 pull the non-inverting input lower when IC2b's output goes low by about 4mV. This shifts the sensor voltage lower by 4mV and the actual sensor voltage needs to increase by 4mV before the IC2a output can switch high again.

When the sensor voltage goes above the high threshold, this is indicated with LED1. For the sensor voltage below the low threshold, LED2 will light instead.

Power for the circuit can come from a 9V or 12V DC plugpack supply or 12V battery.

A 5V regulator (REG1) regulates the supply to provide a fixed voltage for the upper and lower threshold settings. The regulator includes a 100µF bypass capacitors at its input and output for stability.



Pk-Pk(2): 5.50V

Freq(2): 3.51kHz

Scope1: this is the oscillator waveform produced at the output of IC1d. Despite the supply voltage from REG1 being very close to 5V (actually, 5.0372V) the square wave output has some ringing which increases the measured output swing to 5.5V peak-to-peak.

Construction

The *Universal Temperature Alarm* is entirely constructed on a double-sided PCB which can be purchased from the *EPE PCB Service*, coded 03105161 and measuring 78 × 47.6mm.

The completed PCB is housed in a small UB5 (83 × 54 × 31mm) plastic case. For (optional) effect, we used the semi-transparent blue case.

Fig.2 shows the PCB overlay. Begin construction by installing the resistors, using a DMM to check the value of each before inserting into the PCB.

Diodes D1 to D5 can now be installed, taking care to orient correctly. Do note that D5 is a 1N4004, while the remaining diodes are type 1N4148.

IC1 and IC2 can be directly soldered in or IC sockets used. Take care to orient these with the correct polarity. REG1 and Q1 are soldered in now. Don't get them mixed up because these and the temperature sensor look similar, apart from their type markings.

PC stakes can be used for the test points and for the piezo connection points.

The two 100µF electrolytic capacitors need to be installed with the polarity shown and with the top of these no more than 13mm above the top edge of the PCB.

Install the 100nF and 10nF capacitors next. These can be positioned either way round. Then solder in the 2-way pin headers for JP1 and JP2, along with the cell holder.

Trimpots VR1 and VR2 can now be installed. These are oriented with their screw adjusters toward CON2, as shown.

LED1 and LED2 are mounted so the top of the LED lens is 16mm above the top surface of the PCB. Make sure the longer lead of each LED (the anode) is inserted in the 'A' position on the PCB.

The red LED is for LED1, the high LED (marked on the PCB); similarly the blue LED (LED2) is for low.

If your LEDs are clear, it's easy to check their colour using the diode test on a multimeter. An LED should faintly glow to reval the colour under test.

Parts list – Universal Temperature Alarm

1 PCB available from the *EPE PCB Service*, coded 03105161, 78 × 47.6mm
1 UB5 translucent clear or blue case, 83 × 54 × 31mm
1 panel label, 76 × 48mm
1 30mm-diameter piezo transducer
1 2.1 or 2.5mm DC socket, PCB moutning (CON1)
1 3.5mm switched stereo jack socket (CON2)
1 3.5mm mono or stereo jack plug
2 M3 tapped 6mm spacers
2 M3 × 5mm machine screws
2 M3 × 5mm nylon or polycarbonate screws (or cut-down longer threaded screws)
2 2-way pin headers (2.54mm pin spacing) (JP1,JP2)
2 jumper shunts
6 PC stakes
1 1m-length single-core shielded cable
1 35mm-length of 2mm-diameter heatshrink tubing
1 ball point pen casing for temperature probe
Aquarium-rated silicone sealant (Selleys Glass Silicone or equivalent)

Semiconductors
1 LMC6484AIN quad CMOS op amp (IC1)
1 LMC6482AIN dual CMOS op amp (IC2)
1 78L05 5V regulator (REG1)*
1 BC547 NPN transistor (Q1)
1 LM335Z or LM235Z temperature sensor (SENSOR1)
4 1N4148 switching diodes (D1-D4)
1 1N4004 diode (D5)
1 3mm red high brightness LED (LED1)
1 3mm blue high brightness LED (LED2)

*** Variation in the 5V output of REG1 can cause an error of ±0.5°C over the typical range of indoor ambient temperatures. If better stability is required, you can substitute an LP2950.5 regulator, which has the same pinout.**

Capacitors
2 100µF 16V PC electrolytic
3 100nF 63V or 100V MKT polyester *(code 104 or 0.1)*
1 10nF 63V or 100V MKT polyester *(code 103 or 0.01)*

Resistors (0.25W, 1%)
2 1MΩ 3 220kΩ 1 18kΩ 1 16kΩ 2 10kΩ 1 6.8kΩ
1 4.7kΩ 1 2.0kΩ 2 1.6kΩ 2 1kΩ 1 150Ω
2 10kΩ multiturn top adjust trimpots (VR1,VR2)

The piezo transducer is mounted off the PCB, supported on 6mm spacers and secured with M3 screws. Use the two nylon or polycarbonate screws on the underside of the PCB so that there will be no possibility of shorting between tracks and pads.

If necessary, enlarge the mounting holes for the piezo transducer to 3mm to suit the screws. Wires can be soldered to the PC stakes marked 'piezo' on the PCB. Using PC stakes allows for short lengths of heatshrink tubing to be placed over the wires and PC stakes to help prevent the wires from breaking off.

While the piezo transducer will probably come with red and black wires, the connections required are not polarised and it doesn't matter which wire is used for each 'piezo' position.

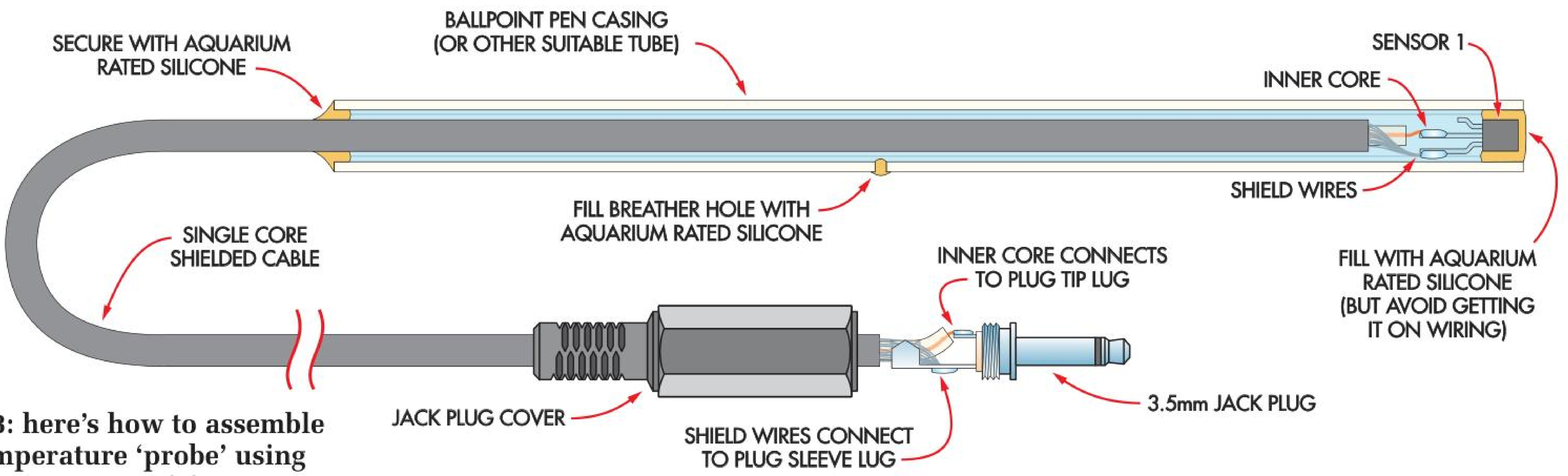
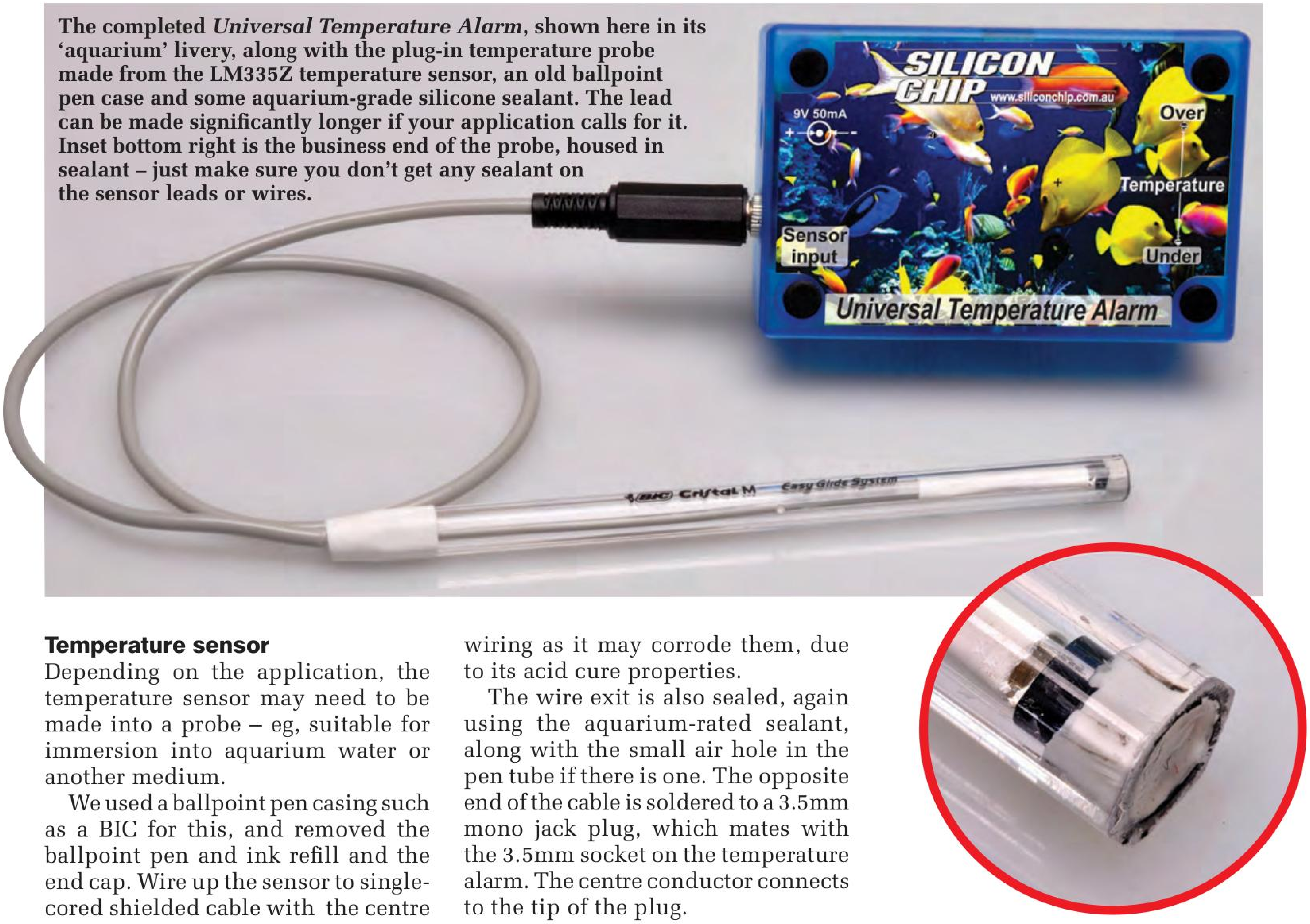

SECURE WITH AQUARIUM RATED SILICONE
BALLPOINT PEN CASING (OR OTHER SUITABLE TUBE)
SENSOR 1
INNER CORE
SHIELD WIRES
FILL BREATHER HOLE WITH AQUARIUM RATED SILICONE
SINGLE CORE SHIELDED CABLE
INNER CORE CONNECTS TO PLUG TIP LUG
FILL WITH AQUARIUM RATED SILICONE (BUT AVOID GETTING IT ON WIRING)
JACK PLUG COVER
3.5mm JACK PLUG
SHIELD WIRES CONNECT TO PLUG SLEEVE LUG

Fig.3: here's how to assemble a temperature 'probe' using the LM335Z precision temperature sensor.



The completed *Universal Temperature Alarm*, shown here in its 'aquarium' livery, along with the plug-in temperature probe made from the LM335Z temperature sensor, an old ballpoint pen case and some aquarium-grade silicone sealant. The lead can be made significantly longer if your application calls for it. Inset bottom right is the business end of the probe, housed in sealant – just make sure you don't get any sealant on the sensor leads or wires.

Temperature sensor

Depending on the application, the temperature sensor may need to be made into a probe – eg, suitable for immersion into aquarium water or another medium.

We used a ballpoint pen casing such as a BIC for this, and removed the ballpoint pen and ink refill and the end cap. Wire up the sensor to single-cored shielded cable with the centre conductor going to the + terminal of the LM335Z (the centre pin) and the shield to the side (See Fig.1 and 3).

Make sure that the shield and centre conductor cannot short together or to the other pin (use short lengths of heatshrink if necessary).

Pass the shielded cable through the narrow end of the tube and position the sensor at the wider end. Use aquarium-rated silicone sealant to make physical contact between the sensor and the inside of the casing and to seal off the end. Make sure the sealant does not make contact with the bare leads on the sensor or the wiring as it may corrode them, due to its acid cure properties.

The wire exit is also sealed, again using the aquarium-rated sealant, along with the small air hole in the pen tube if there is one. The opposite end of the cable is soldered to a 3.5mm mono jack plug, which mates with the 3.5mm socket on the temperature alarm. The centre conductor connects to the tip of the plug.

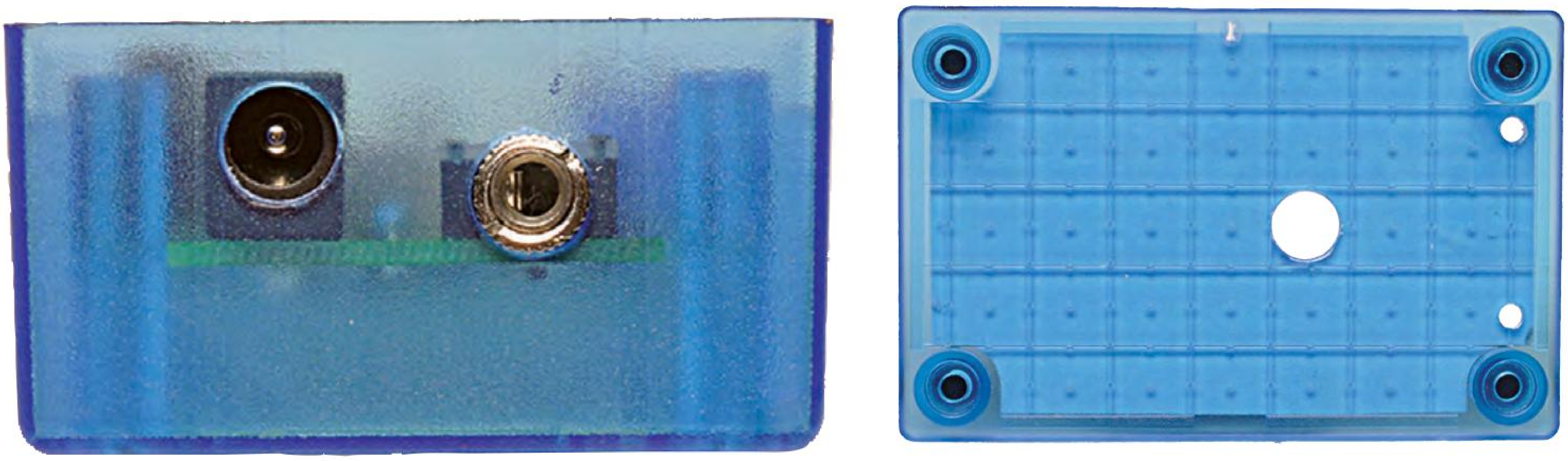
Testing and setting up

Apply power and plug in the sensor. Measure the voltage between TP GND and TPS. Write down the reading and read the air temperature with as accurate a thermometer as you can lay your hands on. Assuming an ambient temperature of 25°C, the voltage should be somewhere around 2.98V. Typical sensors will be 10mV/K, but some may vary from this.

From the temperature reading and voltage, you can work out the voltage per kelvin from your particular sensor. So if you have a reading of 2.95V and the temperature reading on a thermometer is 22°C, this is 295K (you add 273). So 2.95V/295K gives 10mV/K.

A different sensor may give a 3.0V reading for a thermometer reading of 24°C – (297K) which gives 3.0V/297K or 10.1mV/K.

To set the upper and lower thresholds for the *Temperature Alarm*, just calculate the voltage for the temperature required. Table 2 shows how it is done, assuming a 10mV/K sensor. The calculation is done by converting the required °C temperature to kelvin by adding 273 and then multiplying

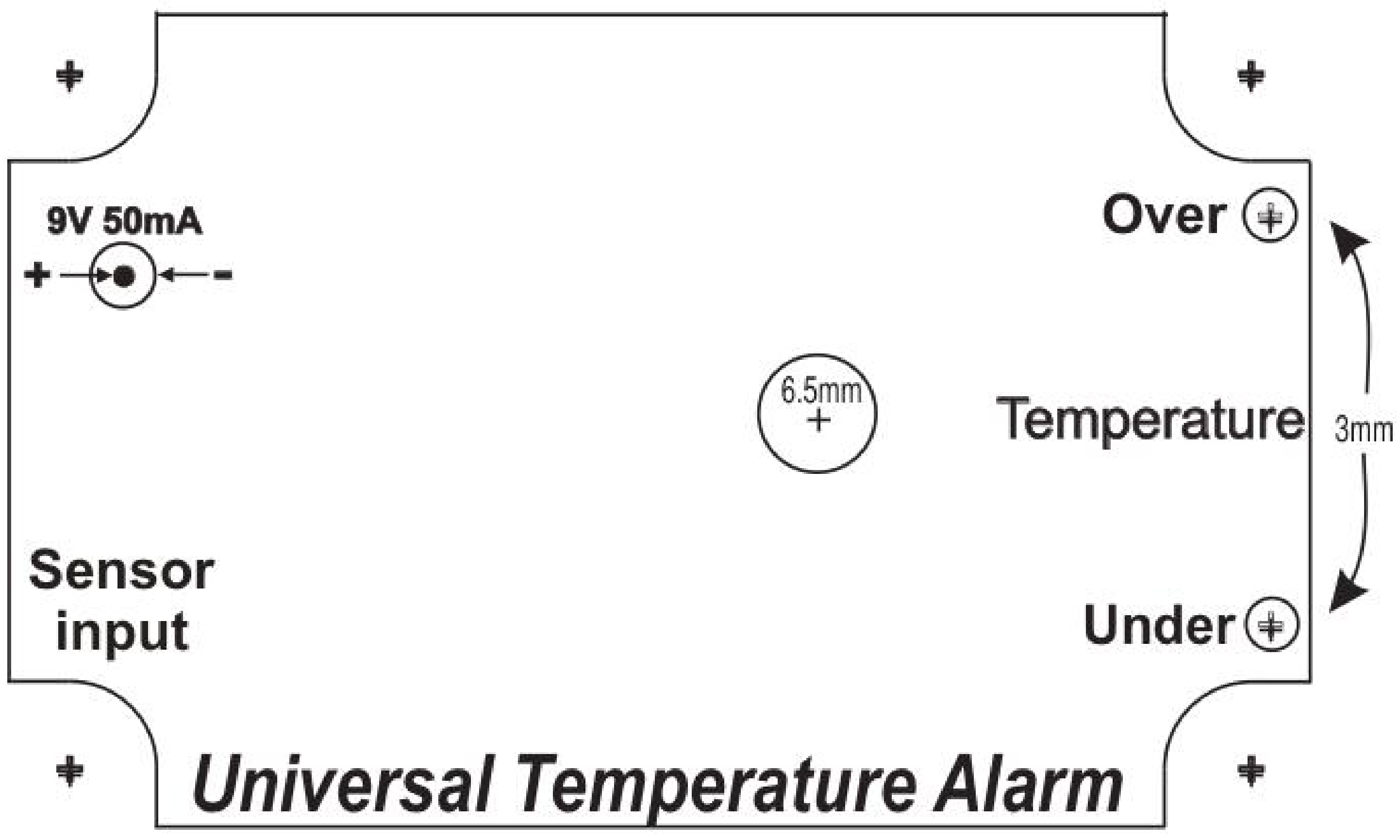


The PCB is designed to snap into the guides moulded into the sides of the jiffy box. Holes are required to be drilled in one end and the lid, as seen above.

Table 2: SENSOR OUTPUT
with respect to kelvin and °C

°C	kelvin (K) (Add 273.15 to °C)	LM335 output assuming 10mV/K
100	373.15	3.7315V
95	368.15	3.6815V
90	363.15	3.6315V
85	358.15	3.5815V
80	353.15	3.5315V
75	348.15	3.4815V
70	343.15	3.4315V
65	338.15	3.3815V
60	333.15	3.3315V
55	328.15	3.2815V
50	323.15	3.2315V
45	318.15	3.1815V
40	313.15	3.1315V
35	308.15	3.0815V
30	303.15	3.0315V
29	302.15	3.0215V
28	301.15	3.0115V
27	300.15	3.0015V
26	299.15	2.9915V
25	298.15	2.9815V
24	297.15	2.9715V
23	296.15	2.9615V
22	295.15	2.9515V
21	294.15	2.9415V
20	293.15	2.9315V
19	292.15	2.9215V
18	291.15	2.9115V
17	290.15	2.9015V
16	289.15	2.8915V
15	288.15	2.8815V
14	287.15	2.8715V
13	286.15	2.8615V
12	285.15	2.8515V
11	284.15	2.8415V
10	283.15	2.8315V
9	282.15	2.8215V
8	281.15	2.8115V
7	280.15	2.8015V
6	279.15	2.7915V
5	278.15	2.7815V
4	277.15	2.7715V
3	276.15	2.7615V
2	275.15	2.7515V
1	274.15	2.7415V
0	273.15	2.7315V

Use this table to set up your *Universal Temperature Alarm*. The areas highlighted are that of most interest to tropical af-fish-ionados; if you need temperatures not an even 5 or 10° above 30°, extrapolate.



Same-size drilling template for the lid of a UB5 Jiffy Box. The 'fishy' version, with holes marked, can be downloaded from the *EPE* website.

A full kit is available from Jaycar Electronics – Cat KC5533

this kelvin value by the mV/K value of your sensor.

So, for example, if you want an upper threshold of 26°C and a lower threshold of 24°C (typical for aquarium use, for example), the voltage from the sensor for these two temperatures is calculated thus: the two temperatures are converted to K; 26 + 273 and 24 + 273. These become 299K and 297K. So for a 10.1mV/K sensor the upper threshold is 10.1mV × 299 = 3.019V and the lower threshold is 10.1mV × 297 = 2.99V.

Setting up the *Universal Temperature Alarm* is done by first setting the upper threshold by adjusting VR1 and monitoring the voltage at TP1 to get the reading required for the upper threshold. Then the lower threshold is adjusted by adjusting VR2 and monitoring TP2 for the lower threshold voltage.

JP1 and JP2 are included so you can select whether you want the upper, lower or both thresholds to sound the alarm. JP1 is inserted for the upper threshold alarm and JP2 for the lower threshold alarm.

Both jumpers inserted will trigger an alarm when either the upper or lower thresholds is exceeded.

Boxing it

The *Temperature Alarm* is installed inside a UB5 case. Holes are required to be drilled in the side for the power input (CON1) and the sensor connector (CON2). A template is available that's included with the front panel artwork. This can be downloaded from the *EPE* website.

Two versions are available: a simple version suitable for general purpose use, or the 'fishy' version shown on our prototype.

The method of producing and attaching your label are up to you, but we suggest paper printed labels should be laminated or otherwise enclosed for protection and longevity. Finally, fit the lid to the case using the four screws supplied with the case.

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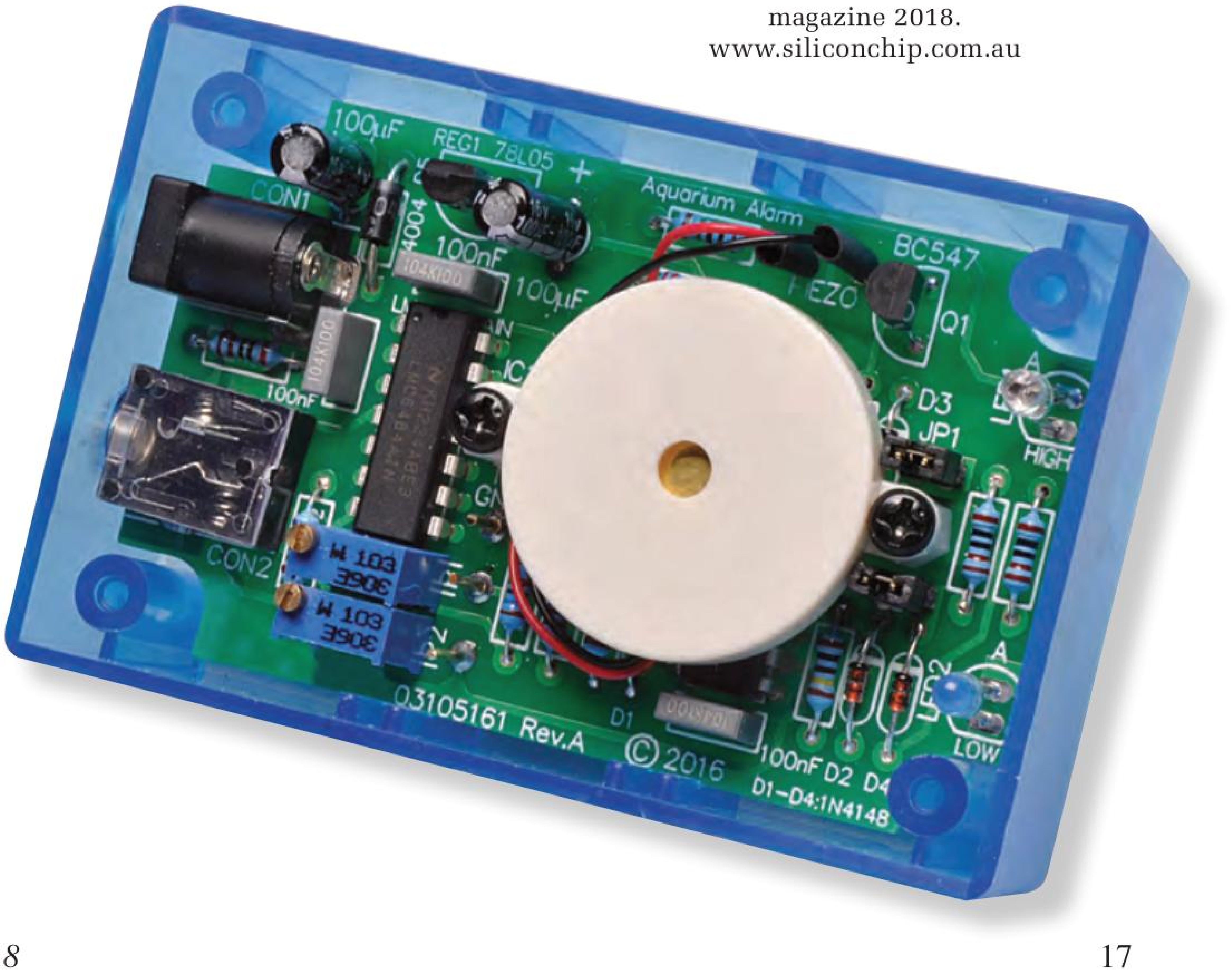

EXCLUSIVE OFFER

Win one of two Microchip AVR Dragon Debuggers

EVERYDAY PRACTICAL ELECTRONICS is offering its readers the chance to win one of two AVR Dragon Debuggers (ATAVRDRAGON).

The Microchip AVR Dragon sets a new standard for low-cost development tools for 8-bit and 32-bit AVR devices with on-chip debug (OCD) capability. The AVR Dragon can perform a symbolic debug on all OCD devices with SPI, JTAG, PDI, high-voltage programming, parallel programming and aWire modes.

The debugger is USB powered, capable of sourcing power to an external target; and the onboard prototype area allows simple programming and debugging without any additional hardware besides strapping cables.

Key features of the Microchip AVR Dragon include: on-board 128Kb SRAM for fast statement-level stepping, full-speed USB-2.0 compliant host interface (12MB/s), robust level converters supporting 1.8V to 5.5V target operation, and support for up to three hardware program breakpoints or one maskable data breakpoint.

A development area lets designers build their own circuitry or add sockets for the desired device footprint. The debugger also supports NanoTrace (depending on the OCD module on the AVR device) using the target device's memory.

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April 2018 ISSUE WINNER

Mr Colin Wilson from Preston, Lancashire

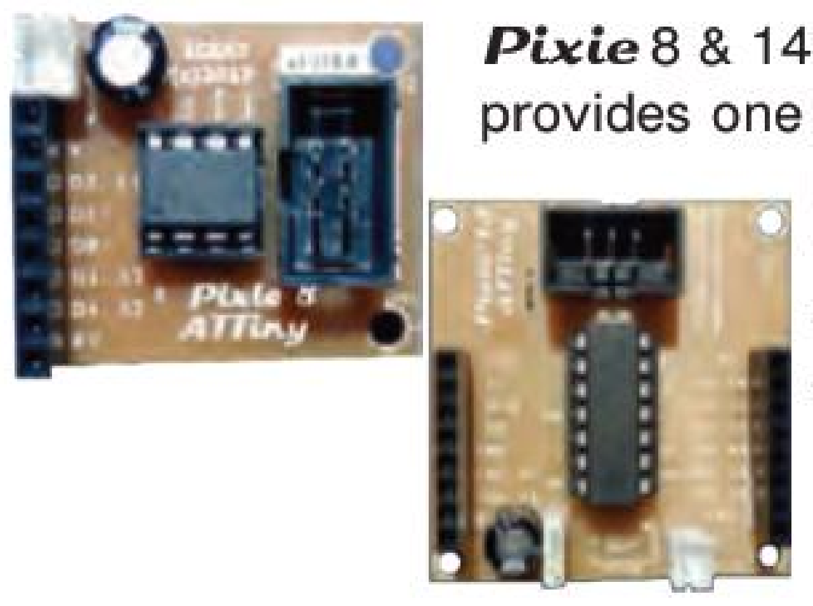
He won a Microchip PICDEM Lab Development Kit, valued at £96.50

CLOSING DATE

The closing date for this offer is 31 August 2018.

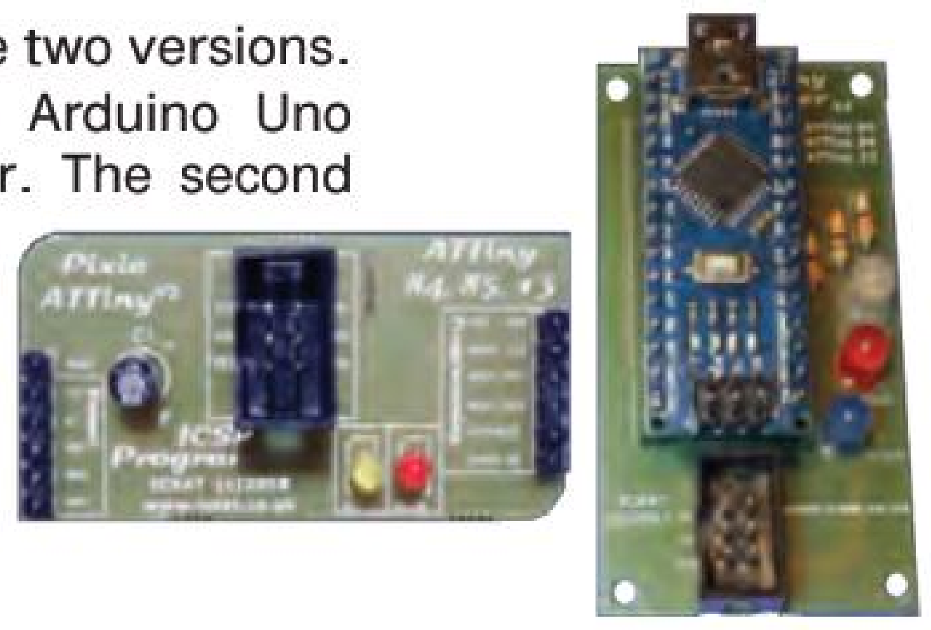
Electronics & Robotics for Makers

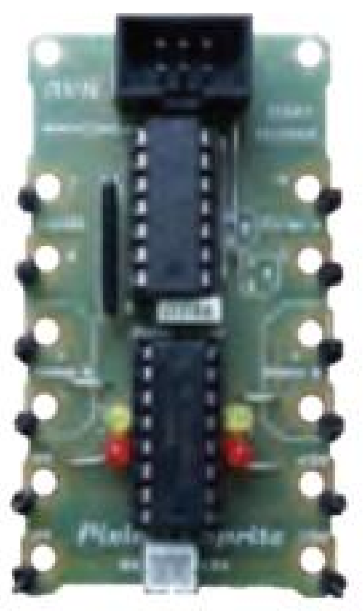
ICSAT's ***Pixie*** system for Education and Hobbyists now adds ATTiny based mainboards to the PICAXE and Genie based versions.



Pixie 8 & 14 mainboards, simple standalone boards that provides one or two standard ***Pixie*** port connectors for power and I/O connections. PICAXE and Genie versions have the 3.5mm download socket and the ATTiny versions have the ATMEL 6 pin ICSP programming connector.

Pixie ATTiny programmers, we have two versions. One that is a mini shield for the Arduino Uno complete with 6 pin ICSP connector. The second one is a complete unit based upon the Arduino Nano, which is pre-programmed and ready to go, you just need to update your Arduino IDE, with the ATTiny board information.





Pixie Sprite is a complete module with I/O connections and 2 bidirectional motor outputs powered by an L293D, and is available in all 3 chip types: PICAXE, Genie and Attiny84. The board can use crocodile clips and 1 pin headers for use with jumpers - a great solution for education and Robotics.

The ***Pixie*** 8 and 14 pin mainboards have one or two ***Pixie*** ports which provides power and I/O connections, all our ***Pixie Dot*** and ***Pixie Hot*** project boards are fully compatible with them.

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MICROMITE

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COMPETITION

This month, ***EPE*** and **micromite.org** are giving you another chance to win a fully assembled 28-pin Micromite BackPack module, complete with 2.8" touchscreen. For details about this powerful, yet compact module, turn to page 12 in the May 2017 edition of ***EPE***.

Micromite
LCD Backpack
RESET
BACKLIGHT

To enter, simply send an email to **epe@micromite.org** with the email subject as: **EM2 Raffle**

Please ensure you email before the closing date: 31 July 2018

The name of the lucky winner will be published in a future edition of ***EPE***.

Look out for future competitions to win other fantastic Micromite products.

WIN A Micromite BackPack!

Good Luck!

T&Cs

1. You may enter as many times as you wish
2. All entries must be received by the closing date
3. Winners will be notified by email within one week after the closing date
4. Winners will need to confirm a valid shipping address to which their prize will be shipped
5. UK winners will have their prize sent via Royal Mail's Special Delivery service
6. Overseas winners will have their prize sent by Royal Mail's International Tracked & Insured service

TOUCHSCREEN APPLIANCE ENERGY METER

Part 2

By JIM ROWE and NICHOLAS VINEN

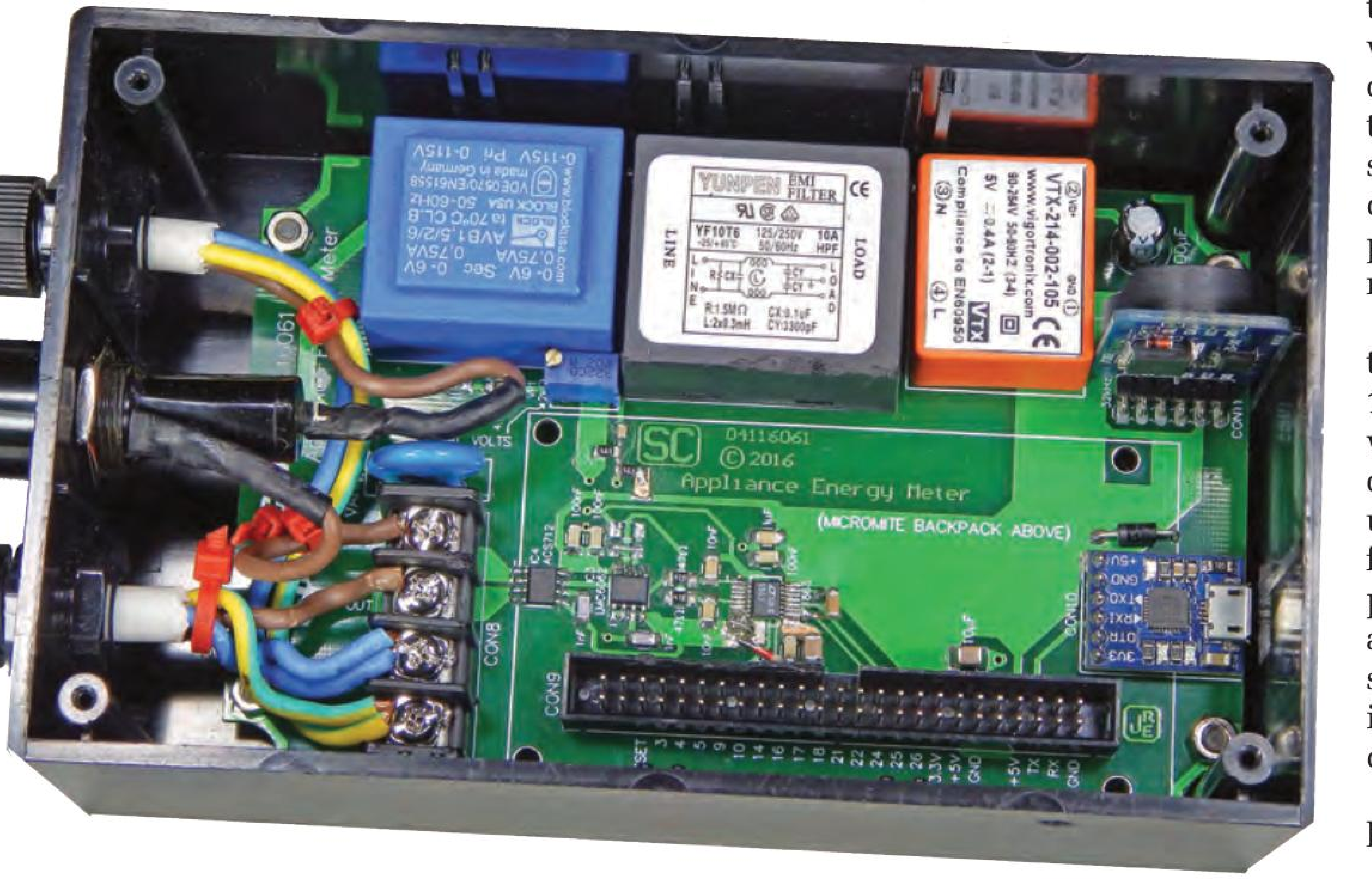
APPLIANCE ENERGY METER
230V AC INPUT
10A FUSE (3AG)
230V AC OUTPUT
USB TO PC
BACKLIGHT
230VAC 35.8W
0.23A 44.1VA
PF=.81 1.371kWh
PEAK - 30c/kWh
$0.37
0 days, 01:17:36
1:48pm 20/06/2016

Last month, we introduced the *Appliance Energy Meter*. It uses a 2.8-inch touchscreen to display energy use data with features such as cost calculation based on time-of-day tariffs, graphing and logging. This second part will take you through the process of building the PCBs and assembling the whole unit, as well as describing some of the interesting features of the meter's software.

The Appliance Energy Meter consists of two modules. The larger PCB hosts the custom circuitry for this project, while the smaller one is used to build the Micromite *LCD BackPack*, which provides all the control, display and user interaction functions.

The *BackPack* module and main PCB fit into a UB1 jiffy box, along with a mains fuseholder and two cable glands to secure the mains wiring. The May 2017 article introducing the *LCD BackPack* has the full construction details, although it's pretty self-explanatory. For UK readers (especially) we recommend buying the *BackPack* from **micromite.org**

Once you've assembled the *BackPack*, including the display, check that it works if you can, but don't go any further. We'll program it after building the main PCB. If you're programming the PIC32 chip on the *BackPack* PCB yourself, now would be a good time to do that.



SMD parts

The main PCB has just three SMD ICs, plus about 20 passive components. Refer to the PCB overlay and wiring diagram, Fig.3. IC2 has a relatively fine pitch, while IC3 and IC4 are easier to solder. So fit IC2 first. This can be done with a standard soldering iron. The only extra tools you need are a good light, some flux paste (available from Jaycar, among other stores), solder wick, flux cleaner (eg, methylated spirits or pure isopropyl alcohol) and some sort of magnifier for checking the solder joints.

There are a few different techniques, but unless you happen to have a hot air or infrared reflow set-up, they're pretty similar. Start by depositing a little solder on one of the corner pads – try not to get solder on any of the other pads. Then you have two options, depending on which you think will be easier.

You can either place the LTC1863 in position, check that all its pins are properly aligned over its pads and that pin 1 (indicated with a dot or divot) is at upper left, as marked on the PCB and shown in Fig.3. Then, while gently pressing the IC down onto the PCB, heat the solder on the pad that you deposited earlier so that the associated pin sinks down into it. Then re-check the positioning and solder the diagonally opposite pin.

Alternatively, you can position the IC next to its pads with pin 1 in the correct orientation and, while heating the solder on that one pad, slide it into position using tweezers or a couple of fingers. Then check that all the pins are correctly located over the associated pads. If not, reheat that solder joint and gently nudge it into position before soldering the diagonally opposite pin.

Either way, you should now have the IC located properly and pinned down so it's just a matter of soldering the remaining pins. You can attempt to do this one at a time, by first applying flux along all the pins and then touching the tip of the soldering iron, loaded with a little solder, onto the very ends of the PCB pads. Alternatively, simply solder the pins two or three at a time, then apply flux paste and use solder wick to remove the excess solder.

Regardless of which method you use, make sure to refresh the solder on those first two pins and use the flux paste and solder wick to clear any bridges between pins. Finally, clean off the flux residue using your solvent of choice and a lint-free cloth, and inspect the IC under a bright light and high magnification to ensure all solder joints are good. If any do not look 100% or you find any bridges, apply some flux and heat (and if necessary, solder wick) until it all looks good.

Then solder IC3 and IC4 using the same technique – you should find them significantly easier due to the larger pins and wider spacing.

The next step is to fit the six SMD resistors and 15 SMD capacitors using a similar technique. Basically, you just tack them in place at one end, then solder the other end before refreshing the initial joint. Make sure that solder flows onto both the PCB pad and the leads of each device.

The resistors will be marked with value codes on the top (eg, 223 or 2222 = 22k). Capacitors will be unmarked, so you will need to take care not to get them mixed up after removing them from their packaging. None of these parts are polarised.

Through-hole components

Now fit through-hole diode D1 with the cathode stripe positioned as shown and then solder a standard 6-way pin header in place for CON10.

Now fit the box header in place for CON9 with the notch towards the top, as shown in Fig.3 and on the PCB silkscreen. Follow with the 1000µF electrolytic, with its longer lead through the pad indicated with the plus sign. You can now fit the 4-way terminal barrier for CON8 along with the USB/serial adaptor board, which is soldered to the pin header already in place on the PCB, with the microUSB socket on the top. MOV1 can then be fitted and it can go in either way around.

IMPORTANT – READ THIS!

We've made a minor circuit change since the first article on the Appliance Energy Meter was published last month.

We've added a 100nF capacitor between the earth terminal on CON8 and the VREF pin (pin 10) of IC2. This reduces the effect of noise from switching regulator REG1 on the operation of the analogue-to-digital converter.

We now only supply the RevI PCB, as shown in the overlay below, which uses an ACS718 (SOIC-16, IC4) and one extra 1nF 0805 capacitor. This is needed as the previous ACS712 current sensor (shown on the schematic last month) had insufficient reinforced voltage rating for double-insulated use.

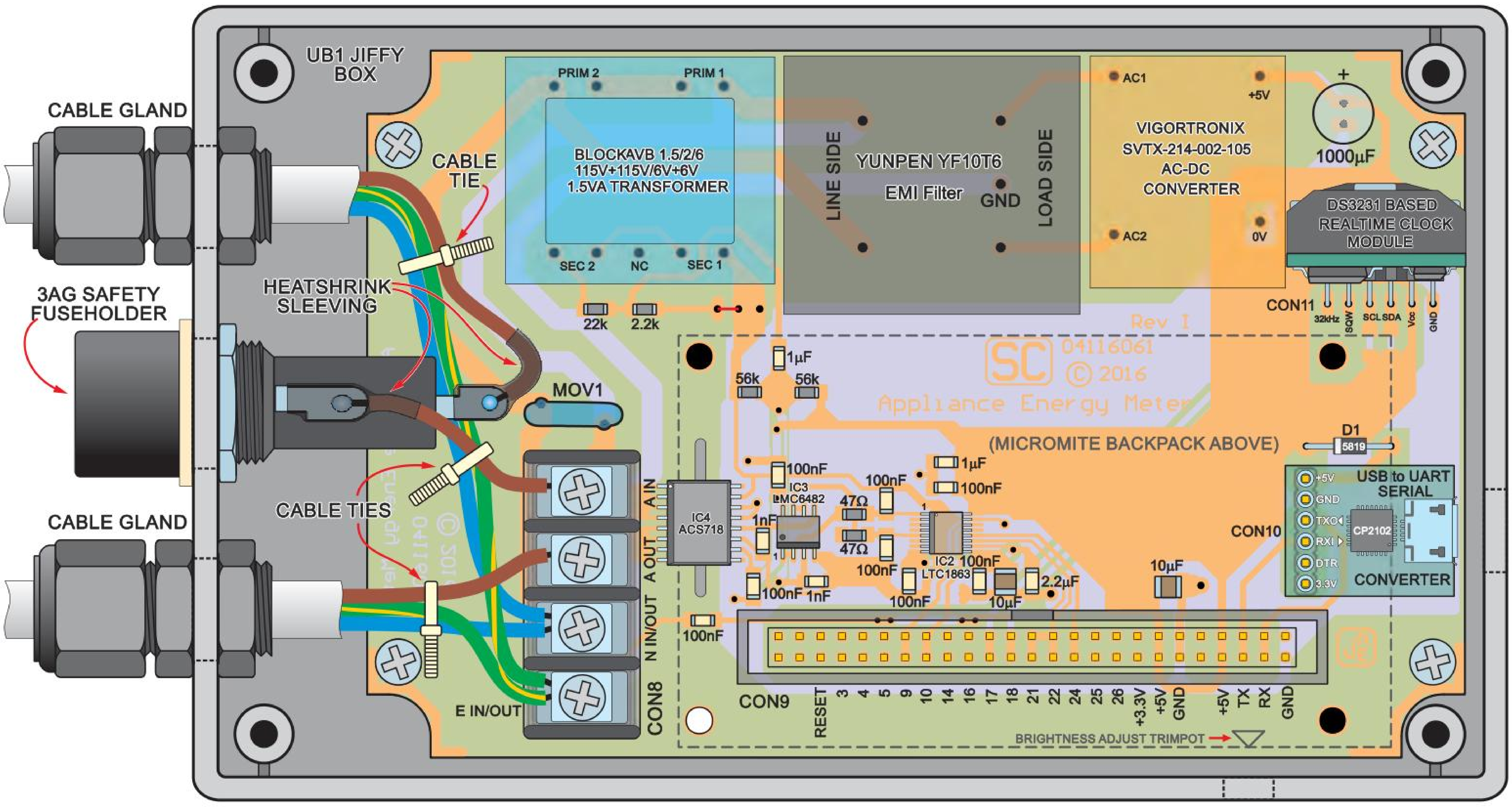
Last, but not least, a very slightly amended schematic with these changes is available for download from this month's section of the EPE website.

That just leaves transformer T1, the EMI filter, the Yunpen AC/DC adaptor and real-time clock modules. Ensure that each one is pushed down fully onto the PCB before soldering its leads. Only the real-time clock module can be installed the wrong way around – it's mounted vertically but make sure that the main body of it sits next to the AC/DC converter; see Fig.3. If unsure, check the labelling on this module's pins and line them up with the corresponding labels on the PCB before soldering.

Note that you will want to fit the button cell to the real-time clock module before soldering it to the board, and if you are using a non-rechargeable (primary) cell, you will need to first desolder the surface-mount, glass-encapsulated diode from the module so that the module won't try to charge it when power is applied.

Making the connecting cable

The *LCD BackPack* and main PCB are joined by a 50-wire IDC cable that's around 60mm in length. You will need to crimp the two 50-way IDC sockets onto either end of the cable as shown in Fig.4. You can either use a vice, with protective pieces of timber on either side of the assembly, or an IDC crimping tool such as the Altronics T1540. We suggest you



UB1 JIFFY BOX
CABLE GLAND
CABLE TIE
HEATSHRINK SLEEVING
3AG SAFETY FUSEHOLDER
CABLE TIES
CABLE GLAND
PRIM 2
PRIM 1
BLOCKAVB 1.5/2/6
115V+115V/6V+6V
1.5VA TRANSFORMER
SEC 2
NC
SEC 1
22k
2.2k
MOV1
LINE SIDE
YUNPEN YF10T6
EMI Filter
GND
LOAD SIDE
AC1
+5V
VIGORTRONIX
SVTX-214-002-105
AC-DC
CONVERTER
AC2
0V
1000µF
DS3231 BASED REALTIME CLOCK MODULE
CON11
32kHz
SQW
SCL
SDA
Vcc
GND
Rev I
SC
04116061
© 2016
Appliance Energy Meter
1µF
56k
56k
(MICROMITE BACKPACK ABOVE)
D1
5819
100nF
IC3
LMC6482
47Ω
47Ω
1nF
100nF
1µF
100nF
IC4
ACS718
IC2
LTC1863
100nF
100nF
100nF
1nF
100nF
2.2µF
10µF
10µF
100nF
A IN
A OUT
N IN/OUT
E IN/OUT
CON8
CON9
RESET
3
4
5
9
10
14
16
17
18
21
22
24
25
26
+3.3V
+5V
GND
+5V
TX
RX
GND
BRIGHTNESS ADJUST TRIMPOT
USB to UART SERIAL CONVERTER
+5V
GND
TXO
RXI
DTR
3.3V
CP2102
CON10

Fig.3: this diagram shows not only the component layout on the PCB, but also its connections and placement within the UB1 Jiffy Box. Take care when identifying (and then soldering) the surface-mount components onto the board – all SMDs should be in position before mounting the transformer, EMI filter, AC-DC converter, serial converter, CON8, 9, 10 and 12.

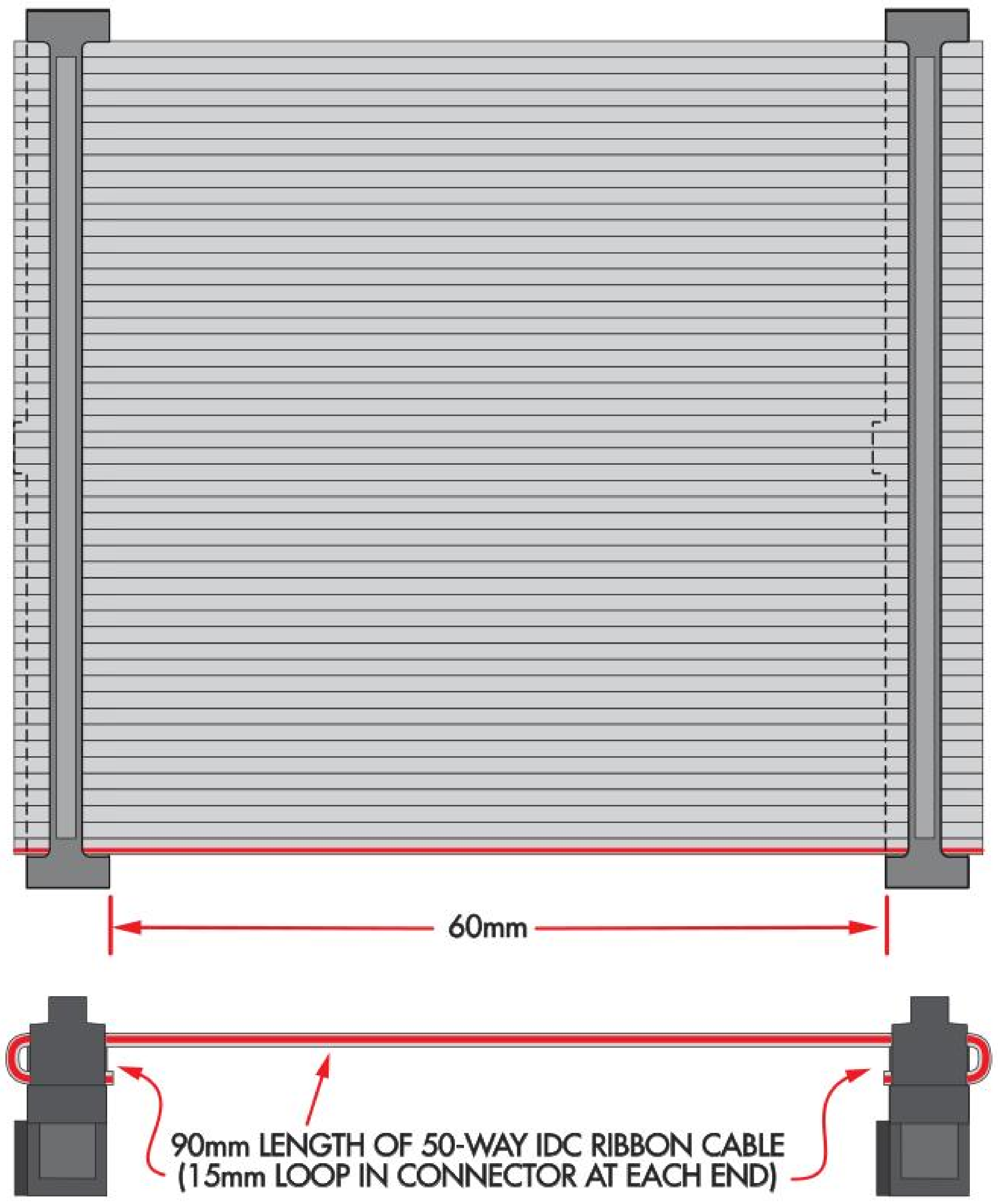

60mm
90mm LENGTH OF 50-WAY IDC RIBBON CABLE
(15mm LOOP IN CONNECTOR AT EACH END)

Fig.4: here's how the IDC cable is made up with its two connectors – note the loop and direction of the cable.

don't use a different tool, such as pliers, because this is likely to result in the plastic connector fracturing.

Once you've made the cable, taking care that the ribbon is properly aligned and the connectors are fully clamped down, the next step is to do some basic checks to make sure everything is working before putting it in the case.

Initial testing

First, plug a microUSB cable into the socket on the main board and plug the other end into your computer. The red LED on the real-time clock module should light up.

If you are using Windows 10, Mac OSX or Linux, the serial port should be automatically identified. If using an older version of Windows, download and install the SILICON CHIP USB serial driver. Verify that a new serial port is available, eg, by running a terminal emulator such as TeraTerm Pro and checking the list. You can open it and type some characters into the terminal, but all that will happen is the LED on the USB/serial adaptor should flash.

Once you've verified that the USB serial port is working, unplug the cable and connect the *BackPack* module to the main PCB, using the ribbon cable you prepared earlier. This can only go into the socket on the main PCB one way, but you will need to be careful to plug it into the *BackPack* with the correct orientation; refer to Fig.5. For the moment, rest the *BackPack* module on your bench top as shown. Note that for clarity, the TFT is not shown fitted on top of the module.

The trick here is to make sure that the GND pin of the *BackPack* goes into either of the right-most holes on the IDC socket. You can then check for continuity between GND points on the two boards to confirm that it is located correctly; for example, place one probe on the via just to the right of the 10µF capacitor immediately to the left of the USB/Serial converter on the main PCB, and the other probe on pin 3 of the *BackPack* ICSP header (CON4).

Now plug the USB cable back in. If you've used a microcontroller that was pre-programmed with the *Appliance Energy Meter* firmware, almost immediately you should see the main screen come up. The readings may not initially all be zero, but they should drop to zero after a few seconds (you may get a current reading of around 60mA since the unit has not been calibrated yet). Touch one of the elements on the screen and verify that it takes you to a different screen.

If your microcontroller has been programmed for the Micromite Mk2, but you do not yet have the *Appliance Energy Meter* software installed, connect to the USB serial port with a terminal emulator set to 38400 baud and press the reset button on the *LCD BackPack*. You should see the Micromite prompt in your terminal emulator. You can then use the multi-step procedure detailed in the side-panel to load the firmware.

Once the software is running, it's a good idea to check that the real-time clock and ADC are working. Checking the real-time clock is quite easy; press on the time and date in the lower-right corner of the screen to set it, then once it has been set, pull out the USB plug and then plug it back in. Once the unit restarts, it should retain the date and time. That indicates the real-time clock and its backup battery are OK.

Testing the ADC is a bit more tricky. If you're getting a zero voltage reading, that's a good sign. However, to be sure, the easiest way is to pass some current between the 'A IN' and 'A OUT' terminals on the PCB (eg, from a DC supply with a current-limiting resistor) and check that it registers on the display.

You can reverse the polarity and you should get a similar reading but note that it won't be exactly the same, as the unit has not been zeroed yet.

If you have a fully programmed *BackPack* but get a blank display, there are a few things that might be wrong. First, check that the ribbon cable has been made properly and correctly plugged in at both ends. Check also that the red LEDs on the real-time clock module and USB/Serial modules are lit. Run a terminal emulator, connect to the USB serial port at 38,400 baud and press the reset button on the *LCD BackPack*. See if you get any error messages which may give you a clue.

For example, if the micro can't communicate with the real-time clock it will issue an error message and halt. You would then need to check that the clock module is soldered

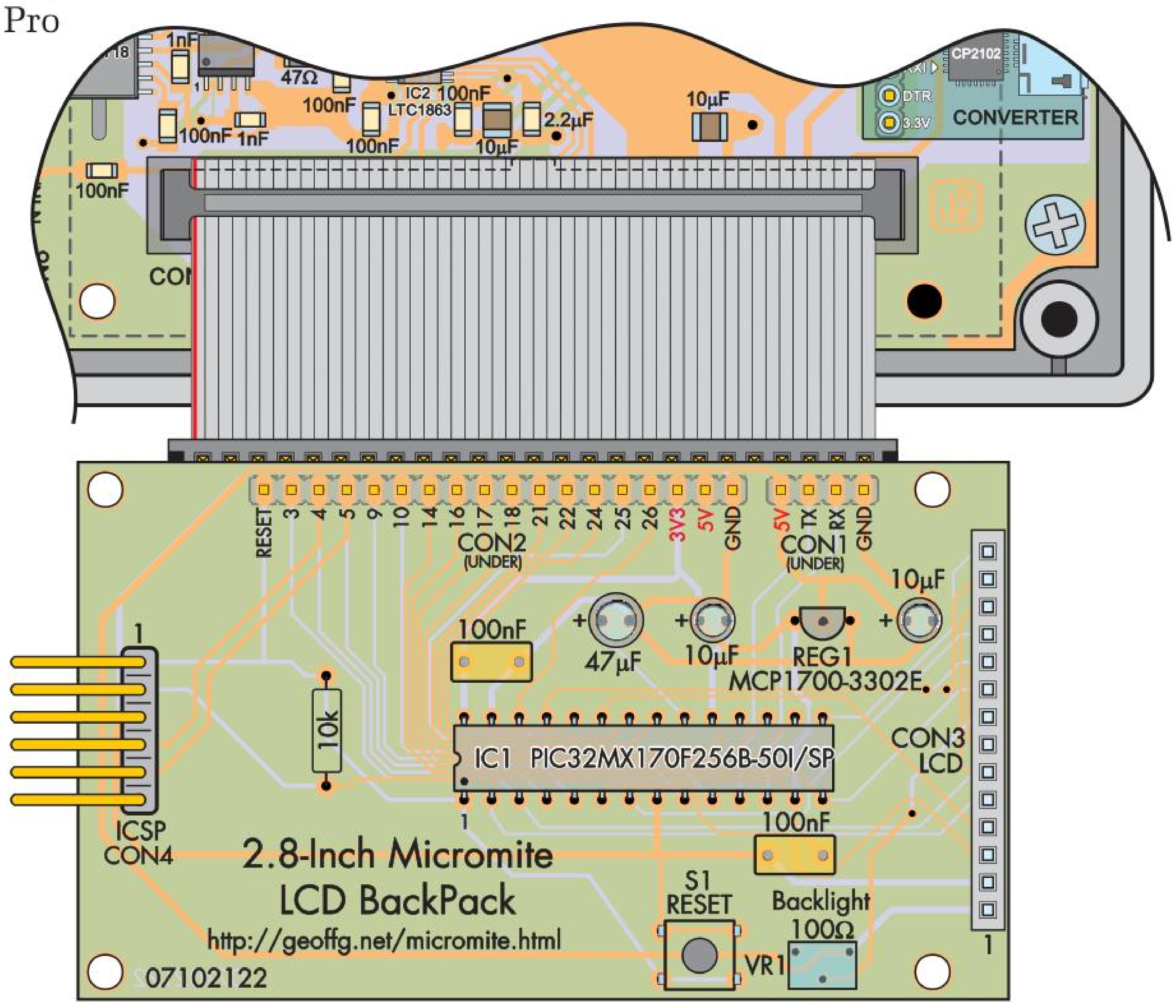


Fig.5: how to connect the *LCD BackPack* to the main PCB for testing (the TFT touch screen is *not* shown for clarity).

properly and oriented correctly.

If you're getting nothing on the display and no error messages over the serial console, there is likely something wrong with the *BackPack* module itself, possibly in the TFT connections or a bad component or solder joint, so check it carefully.

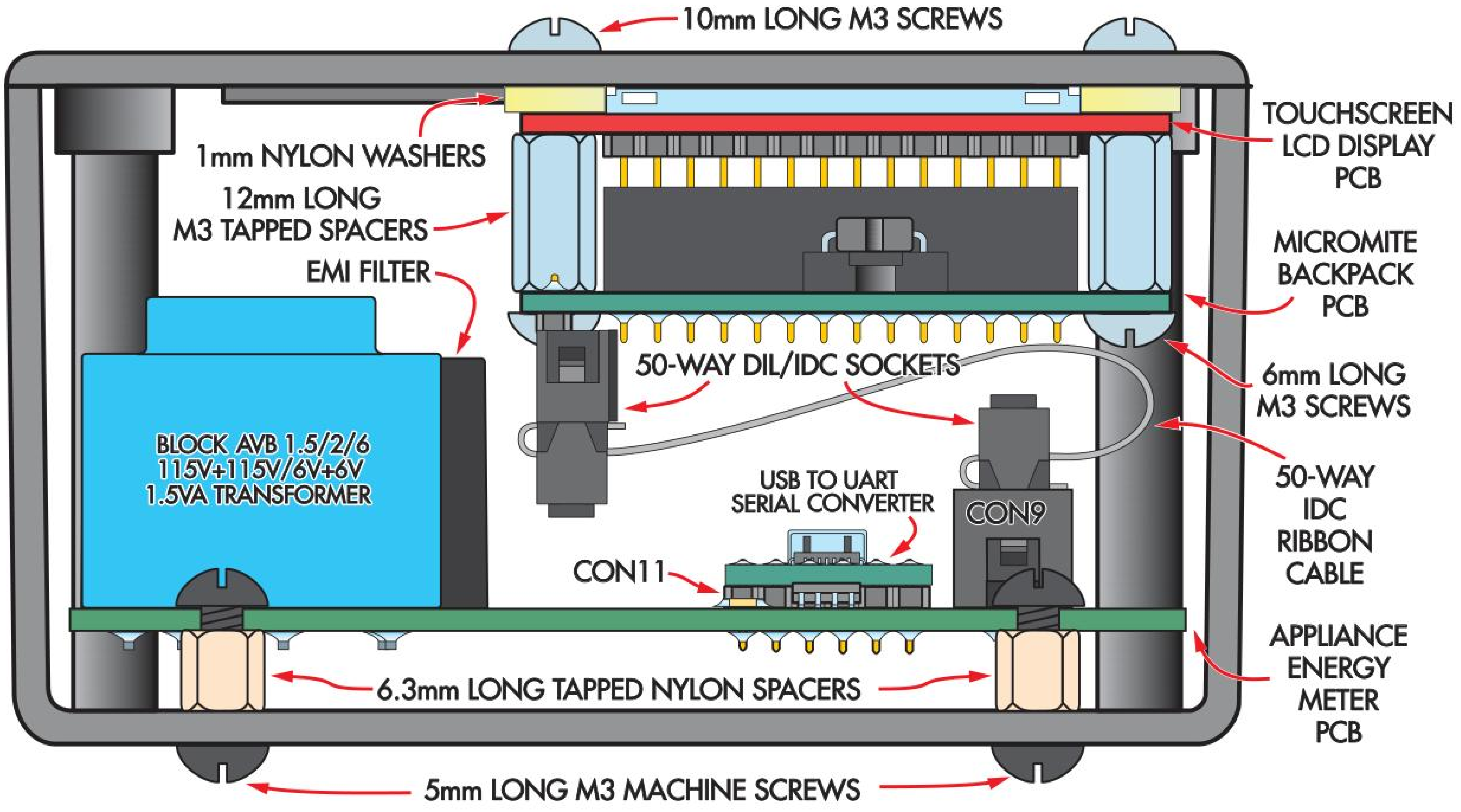

10mm LONG M3 SCREWS
1mm NYLON WASHERS
12mm LONG M3 TAPPED SPACERS
EMI FILTER
TOUCHSCREEN LCD DISPLAY PCB
MICROMITE BACKPACK PCB
6mm LONG M3 SCREWS
50-WAY DIL/IDC SOCKETS
BLOCK AVB 1.5/2/6 115V+115V/6V+6V 1.5VA TRANSFORMER
USB TO UART SERIAL CONVERTER
CON9
CON11
50-WAY IDC RIBBON CABLE
APPLIANCE ENERGY METER PCB
6.3mm LONG TAPPED NYLON SPACERS
5mm LONG M3 MACHINE SCREWS

Fig 6: it's a snug fit, but all the components mount inside the UB1 Jiffy box, as shown here. Compare this and the photo on the first page when assembling. Case drilling details are shown at the end of the article. Note: this diagram is shown oversize, for clarity.

Case preparation

The next step is to prepare the case. First, drill the holes for mounting the main PCB in the base. You can either use the diagrams on the next spread, use the PCB as a template, positioned as far to the right as possible (see Fig.3) or download the drilling diagram from the *EPE* website and use that as a template. The four mounting holes are drilled to 3mm.

Now fit 6.3mm tapped nylon spacers to the inside of the box using 5mm M3 machine screws and tighten them up. We recommend the use of nylon machine screws for the attachment of the spacer at lower left (both top and bottom), which will be closest to the mains wiring when the unit is complete.

If you can't get a 5mm nylon machine screw, use a longer nylon screw fed through an untapped spacer and secured with a nylon nut, although this will be a lot more 'fiddly' to attach.

Now is a good time to attach some rubber feet to the bottom of the box. Adhesive types are the easiest, however you could use slightly longer screws to attach the nylon spacers and also hold screw-on feet in place (but make sure they don't project any more than 3mm into the spacers), or simply drill four extra holes and attach the feet that way.

Before fitting the PCB into the box, drill the three round holes at the left end for the mains cable and fuseholder and make the rectangular cut-out on the right side for access to the USB socket. Details are in the drilling and cutting templates mentioned above and available for download from our website, as well as being shown on the next spread.

Uploading the code to the Micromite chip

Most constructors will simply purchase a pre-programmed PIC or download and install the HEX file which includes MMBasic along with all our code, so that the micro is ready to go. But some readers may wish to modify the code and because we had to resort to some tricks to make it fit, here is the multi-step procedure used to load it.

First, program your PIC32 with the latest version of the MMBasic firmware and establish a serial console connection using the USB converter. You will need to set up the display and touch panel as detailed in the May 2017 article on the *LCD BackPack*. Note that the *BackPack* (and, if attached, the main board) are powered from the PC during the programming process.

The first step is to load **SCAppEnergyMeter_Library.BAS** into the Micromite. First, download the code from the *EPE* website, then grab a copy of Jim Hiley's Windows/Linux 'MMEdit' program. It is freeware and available from **www.c-com.com.au/MMedit.htm** For Windows, download the setup file called **MMEdit.exe** and run it. It works on any Windows version since XP.

Run MMEdit and open the BASIC file mentioned above. Next, ensure the 'Auto crunch on load' option in the Advanced menu is selected and set up the COM port to communicate with the Micromite by selecting the 'New...' option under the Connect menu. You can then click the 'Load and run current code' button, right-most in the toolbar under the menu (with the icon that looks like a blue stick figure). You should get a progress dialog and the upload will take around 30 seconds.

If it fails, close this window and re-check the COM port settings (make sure you don't have this open in another program).

Once the upload is complete, the MMChat console window should automatically appear. You can then execute the 'LIBRARY SAVE' command (note: if you have previously done this, you will need to run 'LIBRARY DELETE' first). After a brief delay, it should display the MMBasic prompt, '>'. You can verify that the code was saved by issuing a 'MEMORY' command, which should yield a response similar to:

```
> memory
Flash:
 0K (0%) Program (0 lines)
 18K (31%) Library
 42K (69%) Free
```

Now open the **SCAppEnergyMeter_Main.BAS** file (which is supplied in the same ZIP as the BASIC file loaded earlier) and, again ensuring that the 'Auto crunch on load 'option is enabled, upload that to the PIC32. The MMChat window should appear once this is complete. You can then type in 'OPTION AUTORUN ON', press enter, then execute the 'RUN' command to start the program.

Note that this will fail, with a real-time clock error, if the *BackPack* is not yet plugged into the main board. Regardless, you can now unplug the USB lead and proceed with the remainder of construction/set-up.

The best approach for the round holes is to start with a small drill (eg, 3mm) and use either a tapered reamer, stepped drill bit or a series of larger drill bits (going up by 1-2mm at a time) so that the holes are nice and round. Once they're large enough, test fit the components, then de-burr the holes using a larger drill bit or countersink tool.

The rectangular cut-out can be made by drilling a series of holes inside the perimeter with a small bit, cutting the remaining plastic to remove the inner piece, then filing the edges smooth and flat with a flat needle file.

The drilling diagrams also show a hole in the front of the box, so that you can access the brightness adjustment trimpot on the *LCD BackPack* board with a small screwdriver. This is optional, however it may be a good idea as it will allow you to reduce the display brightness for lower power consumption during long-term power logging and then increase it again when you want to read the results.

For the lid, a large, rectangular cut-out plus four 3mm mounting holes are required to suit the *LCD BackPack*. It's quite hard to do a neat job cutting the hole for the display. By far the easiest approach is to simply buy a replacement laser-cut black acrylic panel from the SILICON CHIP online shop.

You may need to use longer self-tapping screws than those supplied with the case, as this panel is slightly thicker than the existing lid and lacks the recessed holes for the screw heads – it depends on how long the supplied screws are as this can vary, based on case manufacturer. But it does give a neat appearance and you can still attach a lid label should you wish to. Alternatively, download the cutting diagram and make the holes in the original lid, using a similar technique to the one described above.

Putting it all together

The next step is to fit the 3AG safety fuseholder into the centre hole in the left-hand end of the box, using the pliant washer and mounting nut supplied. Tighten up the nut firmly, with the body of the fuseholder positioned so that the side connection lug is in a position that allows easy access for soldering.

You can then mount the two cable glands. Tighten up the internal nuts to secure the bodies of the glands, but leave the outer nut loose. Now cut the 3m 230V/10A extension cable in half. If you don't have a 60mm length of 10A brown mains wire handy, cut a 60mm-long piece off the input cable (ie, with the 3-pin plug on the end) and strip off its insulation.

Strip 6mm of insulation from one end of the 60mm brown wire and 10-12mm from the other. Solder the shorter bared end to the fuseholder's side connection lug, making sure to produce a reliable joint, then slip a 15mm length of 5-6mm heatshrink sleeving over the joint and shrink it down (eg, using a hot-air gun), making sure it covers as much of the exposed metal as possible.

Now remove about 85mm of the outer sheath from the cut end of the input cable, to free the three insulated wires inside. Cut the brown (live) wire shorter than the others, to about 40mm, and remove about 6mm of the insulation from the end. At the same time, 10-12mm of insulation can be removed from the ends of the blue (neutral) and green/yellow (earth) wires.

Then push all three wires into the box through the input cable gland, at upper left. You may need to remove the outer nut entirely but don't lose the rubber sleeve in the process. Slip another 15mm length of 5-6mm heatshrink tubing over the brown wire and push it all the way down, then solder this wire to the lug at the rear of the fuseholder, making sure you make a secure and reliable joint. Once this has cooled down, slip the heatshrink tubing over the joint and shrink it down.

The next step is to lower the PCB into the case and secure it to the previously installed mounting posts at each corner, using M3 × 5mm machine screws.

As mentioned earlier, use a nylon screw in the lower-left corner. You can then secure the bare end of the wire from the fuseholder under the clamping plate of the top-most terminal of CON8, labelled 'A IN'. Route the wire to the side of the screw furthest from the adjacent terminal and make sure there are no loose strands of copper and that it's screwed down firmly.

Now remove about 40mm of the outer sheath from the end of the remaining half of the extension cable, ie, with the 3-pin socket at its other end. Having done that, strip 10-12mm of insulation from each of the three insulated wires. Push this through the other cable gland and feed the two blue neutral wires (ie, one from this cable and one from the other) into the 'N IN/OUT' terminal of CON8 and clamp them down firmly.

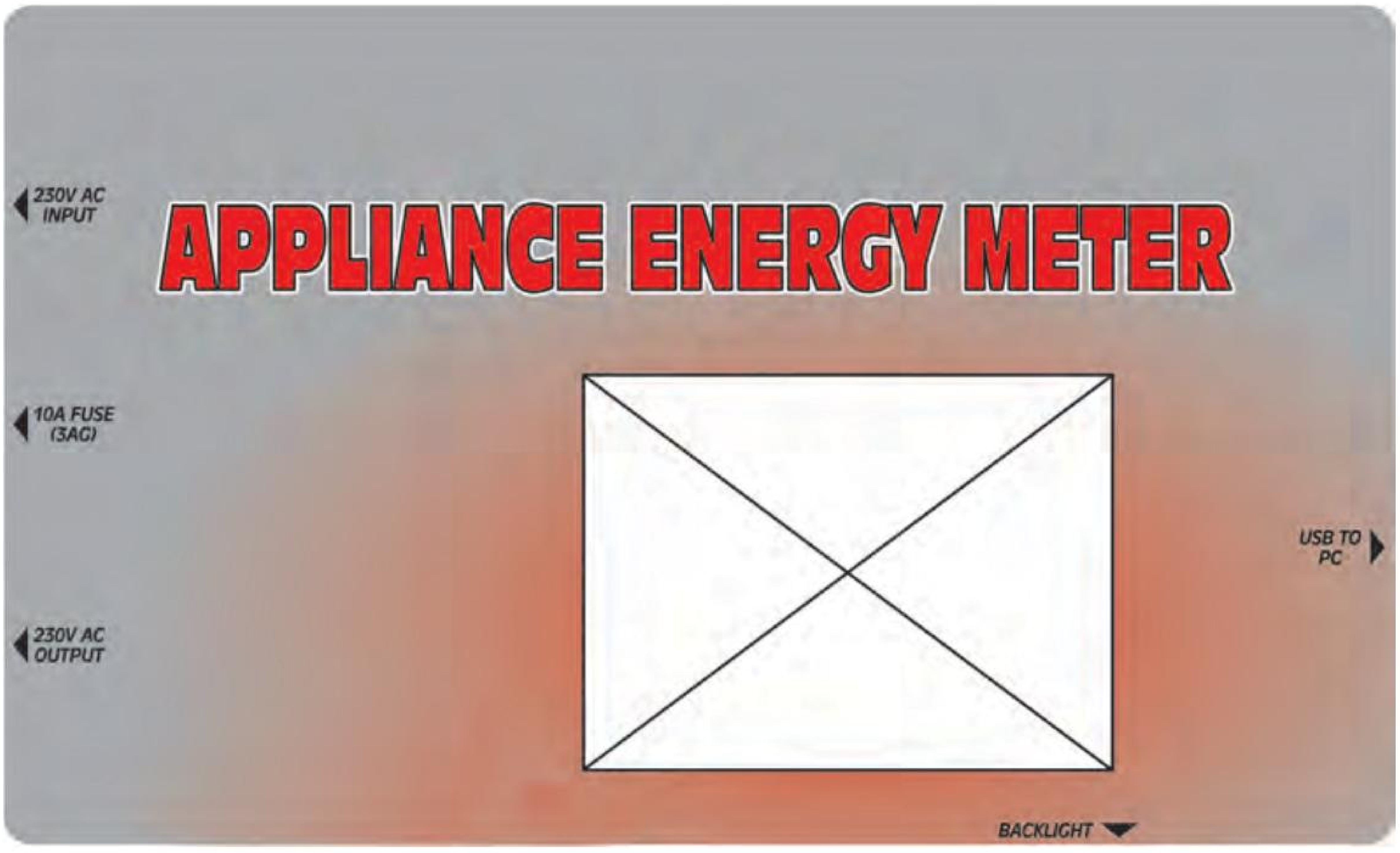
You can now complete the wiring by doing the same with the green/yellow striped earth wires and finally, the brown live output wire; see Fig.3 and the photo for details.

Having completed the wiring, gently pull the two mains leads out of the cable glands until there is only a little slack left on the internal wires, then screw the gland nuts down firmly and add cable ties where shown in Fig.3.

Note that we're going to glue the gland nuts in place later, so that they won't come undone, but we want to do some more testing before making it permanent.

Connecting the BackPack

The *BackPack* can now be secured to the inside of the lid; see Fig.6 for details. Remove the screws holding the LCD onto the spacers and feed four 10mm M3 machine screws through from the top side of the lid.



Front panel artwork (NOT actual size) for the *Appliance Energy Meter* to fit the UB1 Jiffy box specified in the parts list last month. Note that holes are not shown – drilling details are in the diagram oppodite. (Download full-size artwork from the *EPE* website.)

You may want to countersink these holes or use black screws to match the lid.

Pop 1mm-thick nylon spacers (3mm inner diameter, 6mm outer diameter) over the ends of the screws, then feed them into the spacers through the LCD panel, with the brightness adjustment pot towards the edge of the lid.

If you're using the laser-cut lid, you should find that the display fits snugly through the provided cut-out, although you may need to keep the screws loose initially in order to line it up. If using a self-cut lid and it doesn't fit first time, you will have to remove the display and do some filing.

Once it's secured in place, you can attach the ribbon cable as shown in Figs.5 and 6. Again, be careful to ensure that the pins on the *BackPack* are properly aligned with its IDC header and check for GND continuity.

Now would be a good time to attach a label to the lid. Artwork can be downloaded from the *EPE* website. You have various options for producing the label:

1) Print it onto plain or photo paper, then laminate it and either glue it to the lid (eg, using silicone sealant) or attach it using thin double-sided tape.
2) Mirror it and print it onto overhead transparency film, then attach it to the lid using a thin smear of silicone sealant.
3) Use Datapol/Dataflex printable labels (to suit laser printers or inkjet printers respectively).

Regardless of which method you use, cut out the holes for the LCD and mounting screws using a sharp hobby knife before affixing the label to the lid. One advantage of attaching a lid label is that it will cover the non-viewable area of the TFT, for a neater appearance. But since pretty much all interaction is done via the touchscreen, a label is not mandatory.

Before attaching the lid to the box, recheck the mains wiring, especially the wires going into CON8 and make sure that there are no stray strands of copper wire that could short to anything else and that all the connections are secure. Then fold the ribbon cable under the *BackPack* and attach the lid to the box using four black self-tapping screws.

More testing

Now for the real test. Make sure nothing is plugged into the socket end of the mains cable and the lid is securely attached, with no loose wires. Place a fuse in the fuse holder; you can use a 1A fast-blow fuse for now and replace it with a 10A slow-blow fuse as specified later, so that it will blow faster in the unlikely event of a fault.

Place the unit in a secure location where it won't fall off under the weight of the mains cables or be knocked off, then plug it into mains and switch it on. The LCD backlight should be illuminated immediately and the display should come up soon afterwards (you already tested this earlier, so all we are really testing here is the mains power supply).

Verify that the voltage reading is reasonable, ie, around 230VAC, but keep in mind that you haven't calibrated it yet. The current, VA and power readings are not going to be zero for the same reason, but they should drop to a low level after about ten seconds (less than 100mA, less than 10VA and under 5W). If not, that suggests something is wrong so switch off, unplug the unit and check for faults, especially bad solder joints.

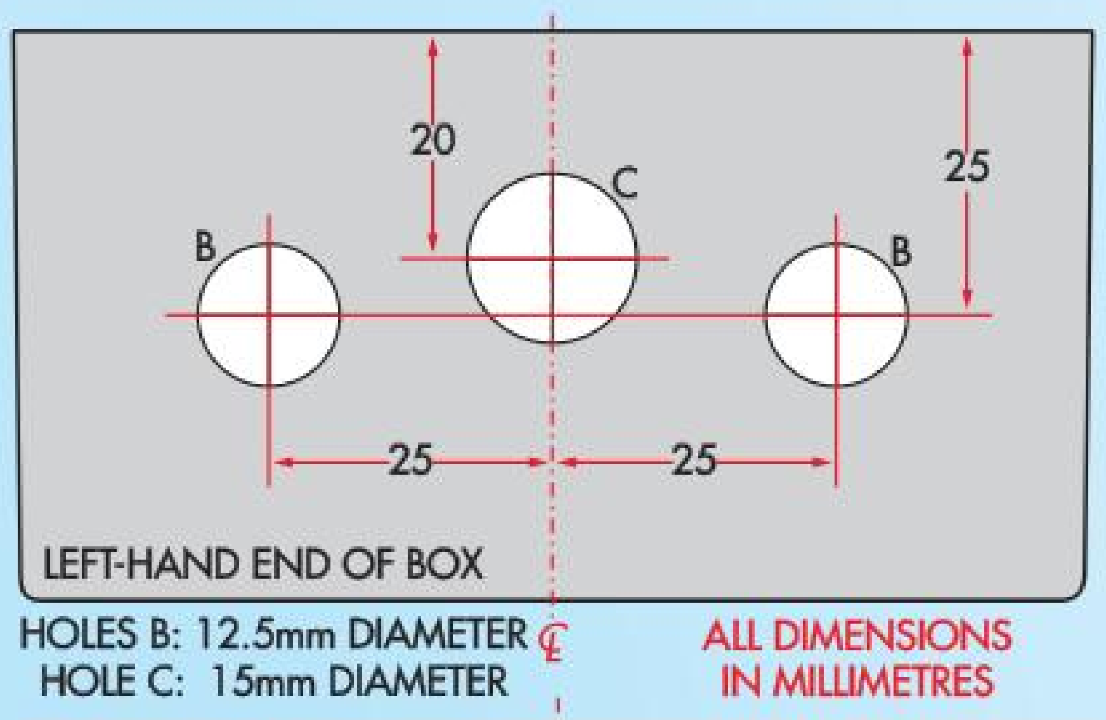
Next month

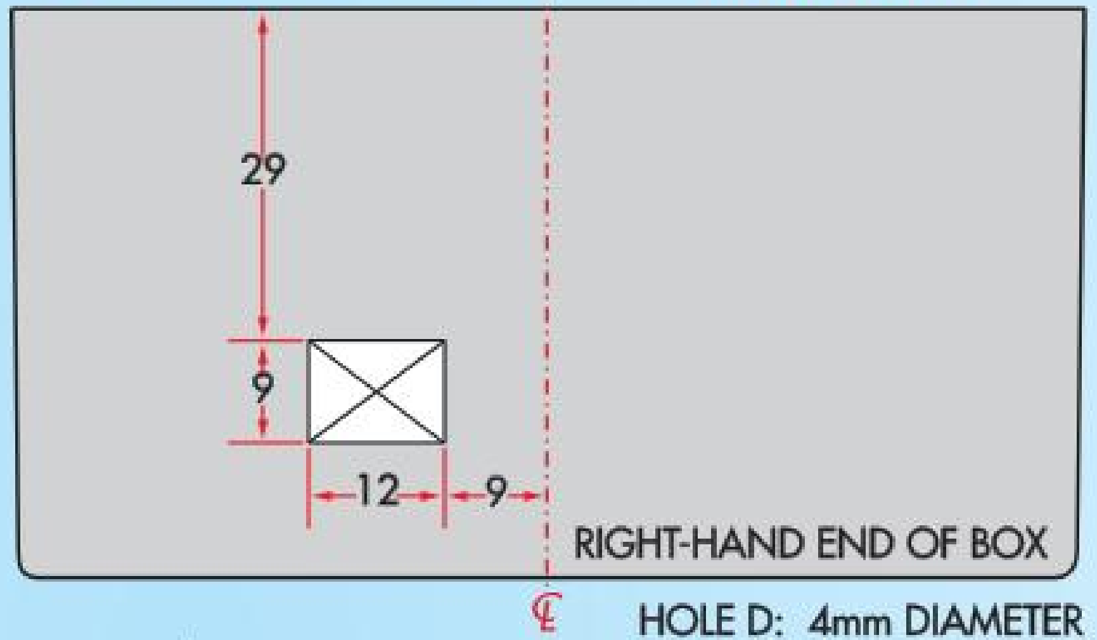
To conclude the *Touchscreen Appliance Energy Meter*, next month we'll go over the calibration procedure and give more information on how to use the unit. We'll also give some details on the CFUNCTIONs we used to augment the BASIC code and provide the required functions for the meter to perform well.

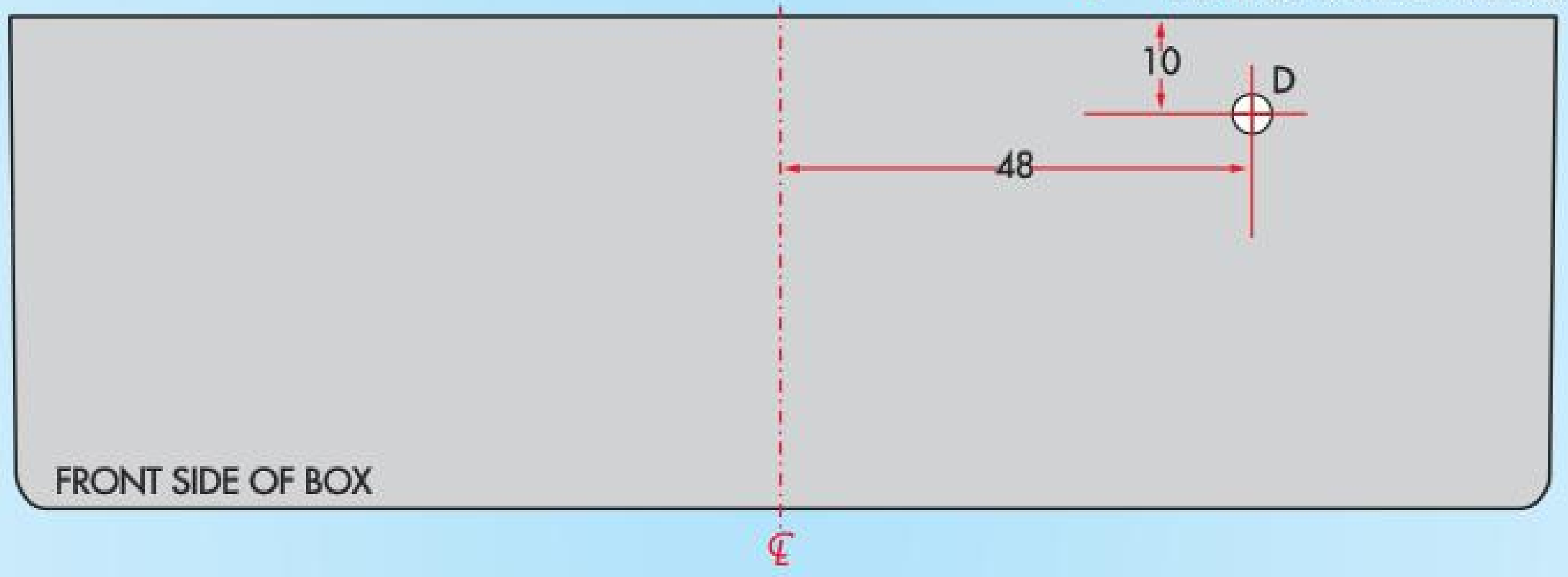
Box drilling and cutting diagrams

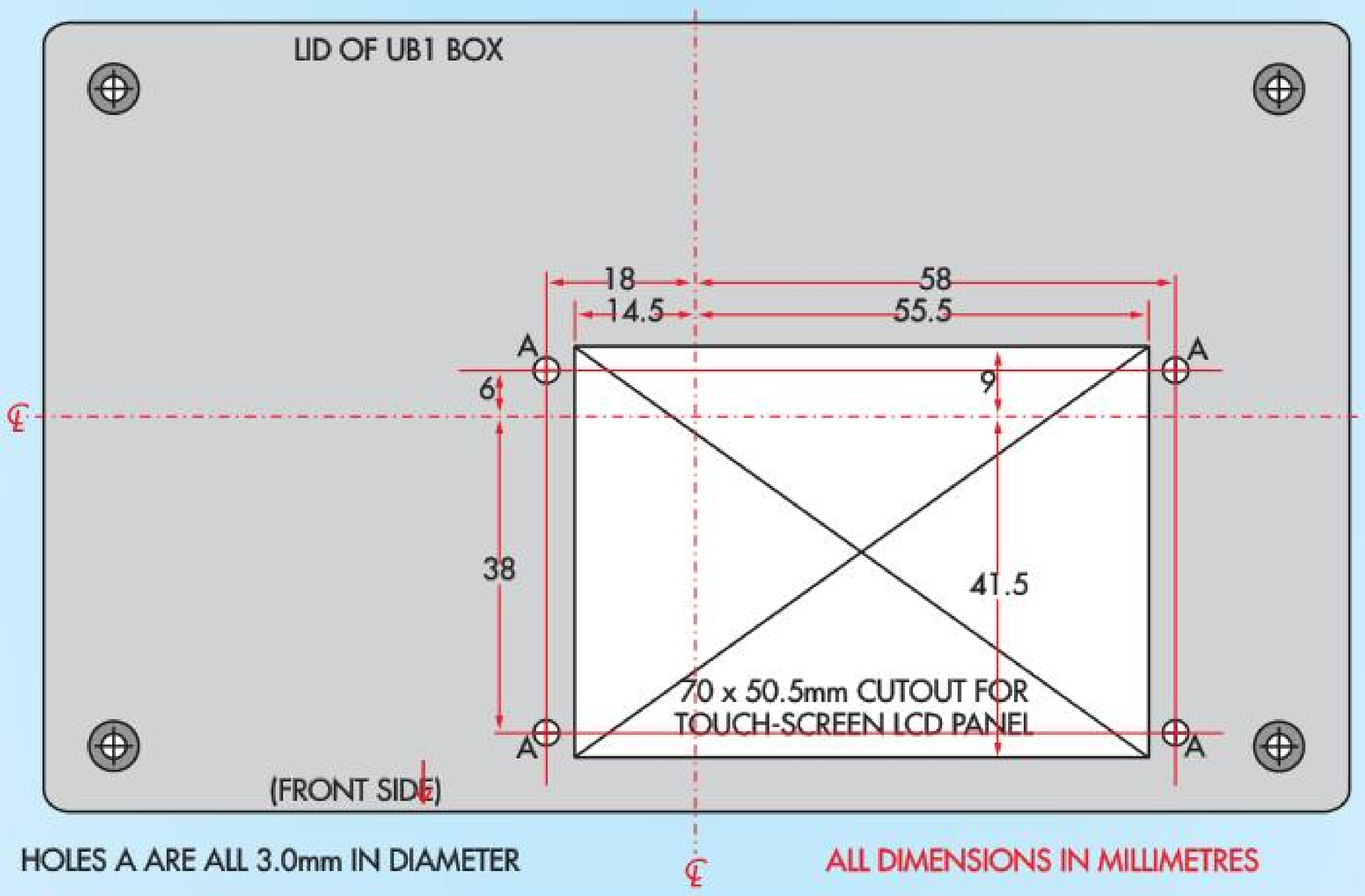
Shown below are the holes and cutouts required in the UB1 Jiffy box. These diagrams are shown exactly half size, so if you enlarge them with a photocopier to 200% they can be used as drilling and cutting templates.

Alternatively, you can download them from the *EPE* website (see the downloads section) and print them at 100% to use them as templates. Colour front panel artwork can also be downloaded from this source.

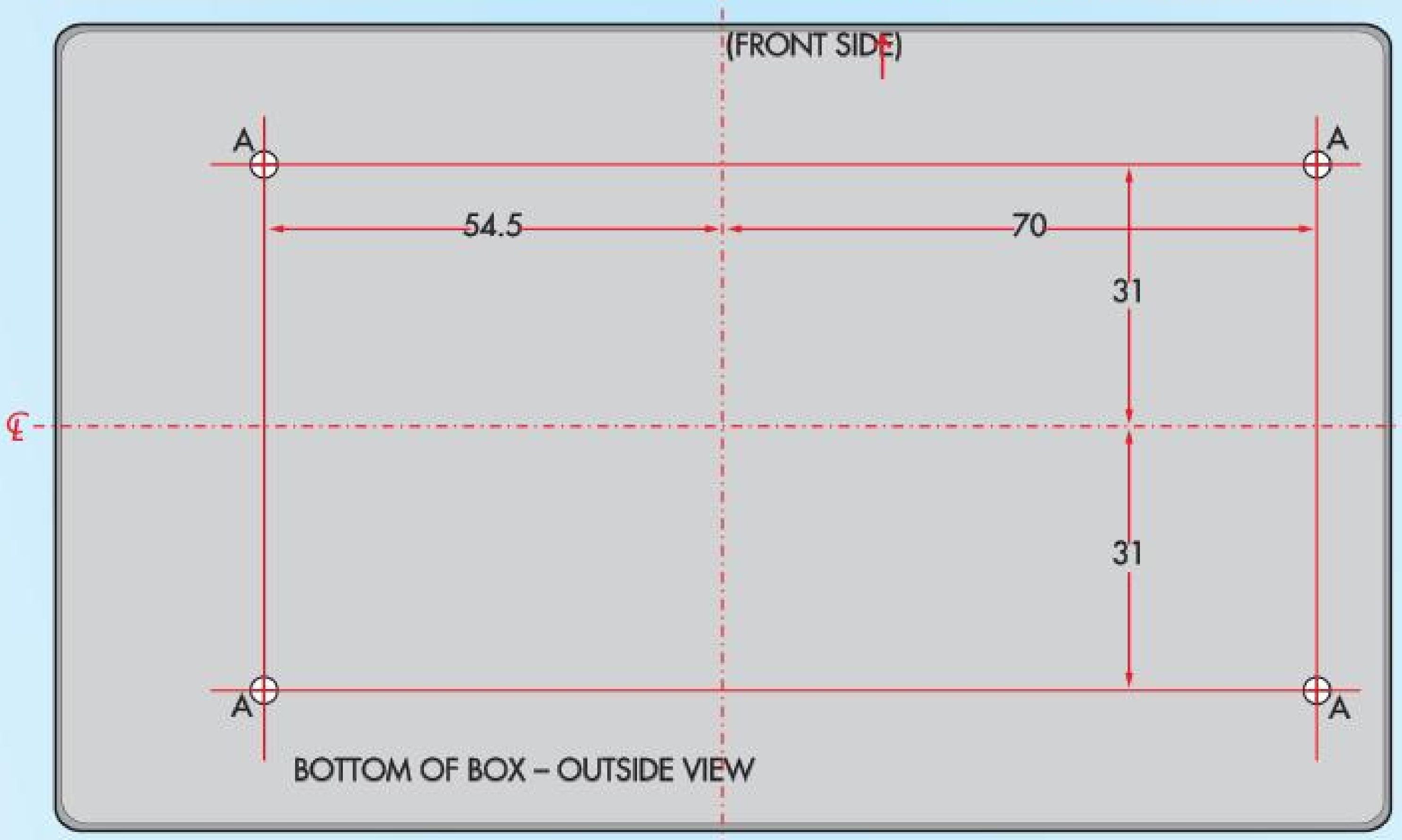








LID OF UB1 BOX
18
58
14.5
55.5
A
A
6
9
℄
38
41.5
70 x 50.5mm CUTOUT FOR TOUCH-SCREEN LCD PANEL
A
A
(FRONT SIDE)
HOLES A ARE ALL 3.0mm IN DIAMETER
℄
ALL DIMENSIONS IN MILLIMETRES



Fitting the software into the Micromite

During the development of this software, we struggled to fit the required functions into the available Flash memory and RAM of the 28-pin Micromite Mk2. While surface-mount PIC32s have up to 512KB Flash and 128KB RAM, the DIP-package versions are limited to 256KB Flash and 64KB RAM, with roughly 50KB of each available to MMBasic.

RAM limitations

Our goal was to be able to log up to one week of data to RAM, with a maximum logging interval of one minute. We managed to compact the voltage, current and power readings into 32 bits (four bytes). So one week of data requires 60 (minutes) x 24 (hours) x 7 (days) x 4 (bytes) = 40,320 bytes of RAM.

After that and taking into account MMBasic's overhead, that left us with about 10KB of RAM. That sounds like a lot, given that our program requires less than 1KB of general variables. Unfortunately though, during software development, we frequently ran out of memory and had to make significant changes to the software to work around this limitation. We also had to frequently rationalise the code so that it (and the fonts) would fit into the 50KB of available Flash program space.

To make matters worse, changes to reduce RAM usage would often increase Flash usage and vice versa. So we had to perform iterative optimisation, reducing the memory footprint, then shrinking the Flash space used, then reducing the memory footprint again and so on until we were able to get all the required functions into the device. Our challenges included:

1) Each MMBasic variable has several hundred bytes of overhead; we're guessing a fixed, relatively large amount of RAM is allocated to store the name of each variable. Just allocating a few integers (nominally 8 bytes each) can easily use up more than 1KB of RAM.
Solutions: Minimise the number of variables used; use arrays where possible (as the name only needs to be stored once); specify a maximum length for all string variables; use local variables wherever possible so that the RAM is freed once we have finished with them; combine multiple flags into a single integer variable; pack configuration data into strings; refactor code to use fewer local variables; do not use constants (making the code messier, unfortunately).

2) Each level of MMBasic function or subroutine recursion uses around 1KB RAM. Therefore, just a few levels of call depth can exhaust available RAM.
Solutions: 'Flatten' functions, ie, when a subroutine or function is only called from one place, integrate it into the 'parent' – this makes the code harder to work with and read but it uses less RAM; use CFUNCTIONs where this can't be avoided, especially for code that must be called in deeply recursed subroutines, as they have much lower stack and variable overhead.

3) Complex string pasting expressions allocate many temporary strings, which can easily add up to several kilobytes.
Solutions: Split up such complex expressions, placing temporary strings into local variables with limited size to reduce RAM usage; perform complex string processing in CFUNCTIONS which don't have this limitation.

4) Fonts and CFUNCTIONs use up a lot of Flash.
Solutions: Use a minimal number of fonts (two, plus the built-in font); place all fonts in the LIBRARY section where they are compressed; also place as many CFUNCTIONs as possible in the LIBRARY section (one of the two will fit).

5) The program is too large to fit in Flash.
Solutions: Place as many extra function as possible in the LIBRARY section, where they are compressed; refactor code to reduce repetition and take advantage of subroutines, recursion and loops (possibly increasing RAM usage); use the MMEdit 'crunch' feature, which strips out unnecessary spaces, comments, etc from the program when uploading to the Micromite; use shorter variable and subroutine names; refactor code to use more compact expressions which perform the same operation; remove any unused or redundant code; hard-code display dimensions.

```
LOCAL INTEGER count, t
LOCAL v, a, pf
LOCAL temp$(8) LENGTH 18
FOR count = 1 TO num_datum-1
  t = (count-1)*log_interval
  v = get_datum(count, “v”)
  a = get_datum(count, “a”)
  pf = get_datum(count, “pf”)
  temp$(1) = STR$(count)
  temp$(2) = STR$(t)
  temp$(3) = duration_str$(t)
  temp$(4) = STR$(v,0,1)
  temp$(5) = STR$(a,0,3)
  temp$(6) = STR$(v*a,0,1)
  temp$(7) = STR$(v*a*pf,0,1)
  temp$(8) = STR$(pf,1,2)
  print temp$(1)+”,”+temp$(2)+”,”+temp$(3)+”,”+temp
$(4)+”,”+temp$(5)+”,”+temp$(6)+”,”+temp$(7)+”,”+te
mp$(8)
NEXT count
```

This code snippet from the logging output portion of the code shows how using string arrays with fixed length can be used to paste multiple values together with lower memory overhead than simply using a single, long expression.

```
   long long int main(const char* date, const char* time,
const
  char* tariff_times, const char* holidays) {
    unsigned int i, day, mon, year, hour, min, dow, offset;
    day = bcd2_to_int(date+1);
    mon = bcd2_to_int(date+1+3);
    year = bcd2_to_int(date+1+8);
    if( dow > 0 && dow < 6 ) {
      for( i = 0; i < 22; ++i ) {
        int holday, holmon, holyear;
        holday = bcd2_to_int(holidays+1 + i*6);
        holmon = bcd2_to_int(holidays+1 + i*6 + 2);
        holyear = bcd2_to_int(holidays+1 + i*6 + 4);
        if( holday == day && holmon == mon && holyear ==
year)           {// it’s a public holiday, woohoo
          dow = 0;
          break;
        }
      }
    }
    ...
```

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This partial CFUNCTION shows how the lower function call overhead and ability to pass pointers into strings eliminates the memory associated with temporary sub-strings.

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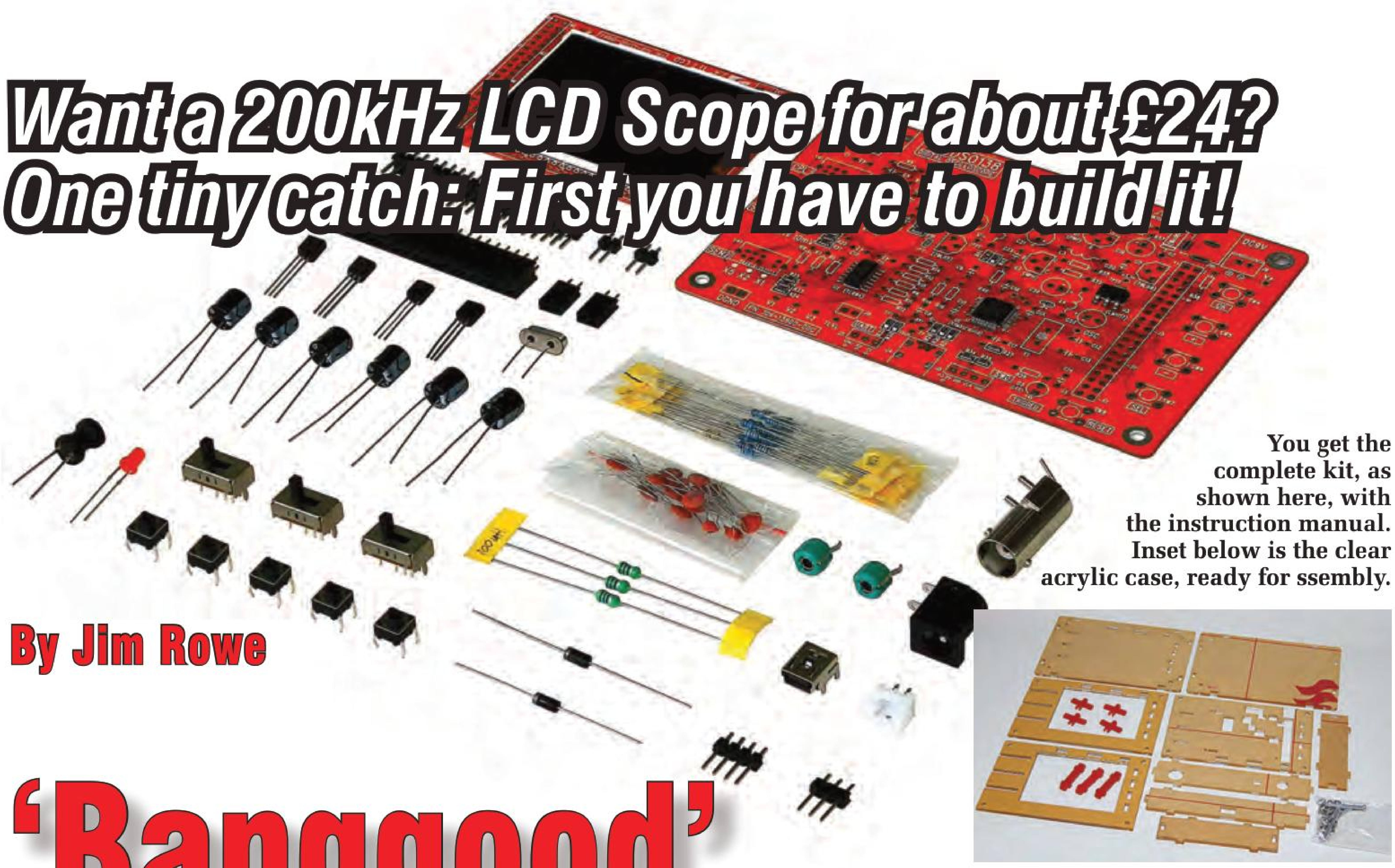


You get the complete kit, as shown here, with the instruction manual. Inset below is the clear acrylic case, ready for ssembly.

By Jim Rowe

‘Banggood’ DSO138 LCD Scope Kit

We’ve looked at some very cheap modules from China recently. Here’s one that more-or-less fits into the same category – except that for the princely sum of £24 (or less!), you get a real, working digital sampling oscilloscope kit. It’s from Banggood and you really get a good bang for your buck!

Sixty or so years ago, the only way that most people could acquire even a basic oscilloscope was to build it yourself, using components salvaged from war-surplus equipment. Even then, by-and-large, most were only ‘audio’ scopes with, perhaps, 10kHz bandwidth. Commercial scopes were so expensive that they could only be afforded by large manufacturers and research labs.

That was back in the valve era and things soon began to change for the better when the solid-state revolution got under way. Before long, the cost of commercial scopes started to fall, while at the same time their performance climbed steadily, especially in terms of analogue bandwidth.

But the real breakthrough came with digital sampling scopes and particularly when cheap LCDs (liquid-crystal displays) started to replace the costly CRTs (cathode-ray tubes) which formed the heart of all the early scopes. This eliminated the need for an expensive high voltage power supply and also enabled many useful features to be added while the cost of scopes continued to plummet.

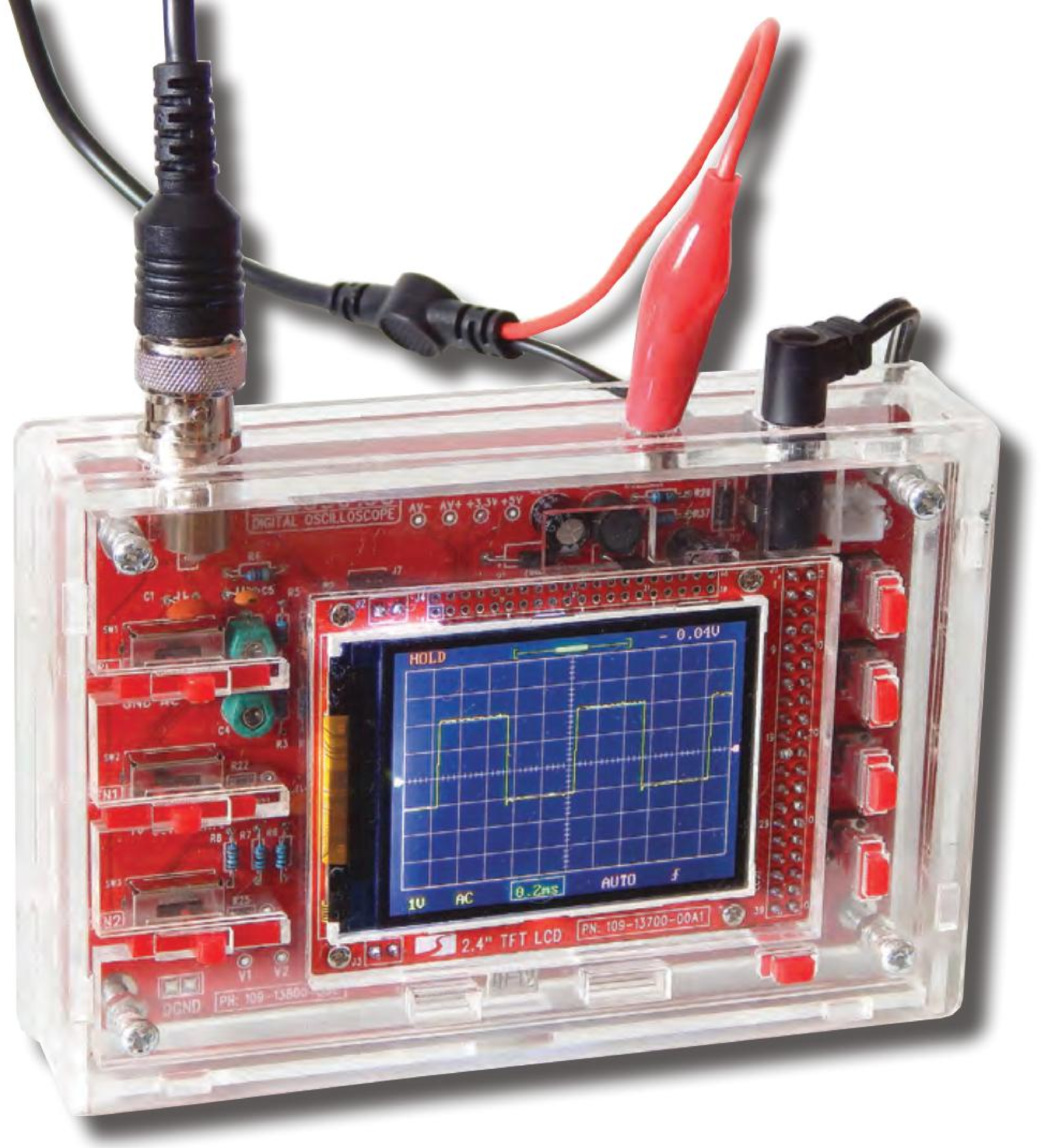
Nowadays, you can buy a wide selection of digital sampling oscilloscopes or ‘DSOs’ at quite reasonable prices. Handheld, single-channel, battery-operated units with 10MHz analogue bandwidth are available for a couple of hundred pounds, while 4-channel 100MHz bandwidth benchtop models cost less than £600. You can even get a 2-channel 300MHz MSO (mixed signal oscilloscope) for around £250.

What if you only need a scope occasionally, and don’t need a lot of bandwidth – for example, if you’re mainly working on audio equipment? This would make it hard to justify an outlay of even £200. But the kit described here is less than a 1/10th of that amount – £15.99 with postage!

It’s known as the ‘DSO138’ and recently has become very popular all around the world. It’s available from online retailer Banggood, which has its main office and warehouse in Guangzhou, China. The firm has over 1000 employees with offices in nearby Shenzhen and Hong Kong, as well as Hangzhou and Yiwu, plus offices in the UK and USA.

The electronics part of the kit is manufactured by the firm JYE Tech Ltd, based in Guangxi, China. The manufacturer of the laser-cut acrylic sheet parts, which are used to make up its custom acrylic case (as shown in the photo of the completed unit opposite) is not specified, but is presumably also in China.

If you look at the Banggood website (**www.banggood.com**), you’ll find that the DSO138 kit is available in two forms: one with all of the SMD components already soldered in place on the main PCB, leaving only the through-hole components for you to fit and solder, and one with just the SMD CPU pre-soldered. We’re reviewing the version with all SMDs



Completed and working – here displaying its own 1kHz calibration square wave. We purchased the optional clear plastic case – the kit is also available without case

pre-soldered, known as the 13803K (product ID 1051616).

The other version is known as the 13804K, and is currently available from Banggood for £23.79, also with case and free delivery (product ID 1051617).

So it not only costs more, but you have more work to do building it up. You can see why we chose the 13803K version to review! By the way, both versions are also available without the matching assemble-it-yourself acrylic case. But if you want to buy it later, or you need to replace it, it's available separately from Banggood for only £4.80 including delivery (product ID 1034768).

The electronics

Apart from the DSO138's 2.4-inch colour TFT LCD screen (320 × 240 pixel resolution), which is mounted on a small PCB of its own, all the rest of the kit's electronics mount on a single PCB measuring 117 × 76mm. And as noted above, the PCB in the 13803K kit has all of the SMD parts already fitted: nineteen 0805 resistors, two ICs and an LM1117-3.3 LDO regulator in a TO-263 package. Everything else in the kit is in the form of through-hole components and connectors for you to fit yourself.

The two ICs are a TL084 quad op amp, used for processing the analogue input signal and generating trigger pulses, and the STM32F103C8 CPU, which does everything else.

The STM32F103Cx is in a QFP-48 package and is a 72MHz, 32-bit ARM Cortex-M3 processor, with the following features: 64KB of Flash memory, 20KB of SRAM, two 12-bit/1MHz ADCs providing up to 16 analogue input channels, seven different timers, a full-speed USB 2.0 interface, two I^{2}C interfaces, two SPI interfaces (18Mb/s), three USART interfaces and a 7-channel DMA controller.

So it's quite capable of doing all of the sampling, display and other work needed to perform the functions of a basic audio DSO – with the right firmware, of course.

Assembling the PCB is fairly straightforward because JYE Tech has provided the kit with a double-sided A4 instruction sheet with 22 numbered assembly step boxes – each one accompanied by a small but clear colour illustration. Each step also has a checklist, allowing you to tick each component's box as you fit it.

The instruction sheet has quite a few helpful hints, like advising you to check the value of each resistor with your DMM before soldering it into the PCB. This is good advice, because the coloured bands on the tiny 1/8W resistors are hard to see even with a magnifying glass.

There's also a guide to checking the voltages on the DSO138's main PCB following assembly, attaching the LCD board and then giving it a basic functional checkout. Plus, there's a troubleshooting flowchart, an explanation of the self-test mode built into the firmware and a picture of the main PCB showing the location of all important test points.

By the way, a PDF file of the instructions can be downloaded from the JYE Tech website (**www.jyetech.com**), so you can preview it before buying the kit and you can also download another copy if you lose or damage the original.

There's a second instruction sheet in the kit, intended to familiarise you with the DSO's various controls and their use. In addition, there's a section on using the built-in 1kHz squarewave signal to adjust the frequency compensation of its input divider and any divider probe you connect to its input. There's also a specification panel, plus a full schematic of the scope on the back of this second sheet. In short, the PCB has been carefully designed to be easy to build and get going.

The JYE Tech website also has a four-page booklet you can download, explaining how to upgrade the firmware in its CPU, an eight-page booklet explaining how to use the library of functions built into its firmware and a single sheet showing an overlay diagram of the main PCB.

Assembling the box

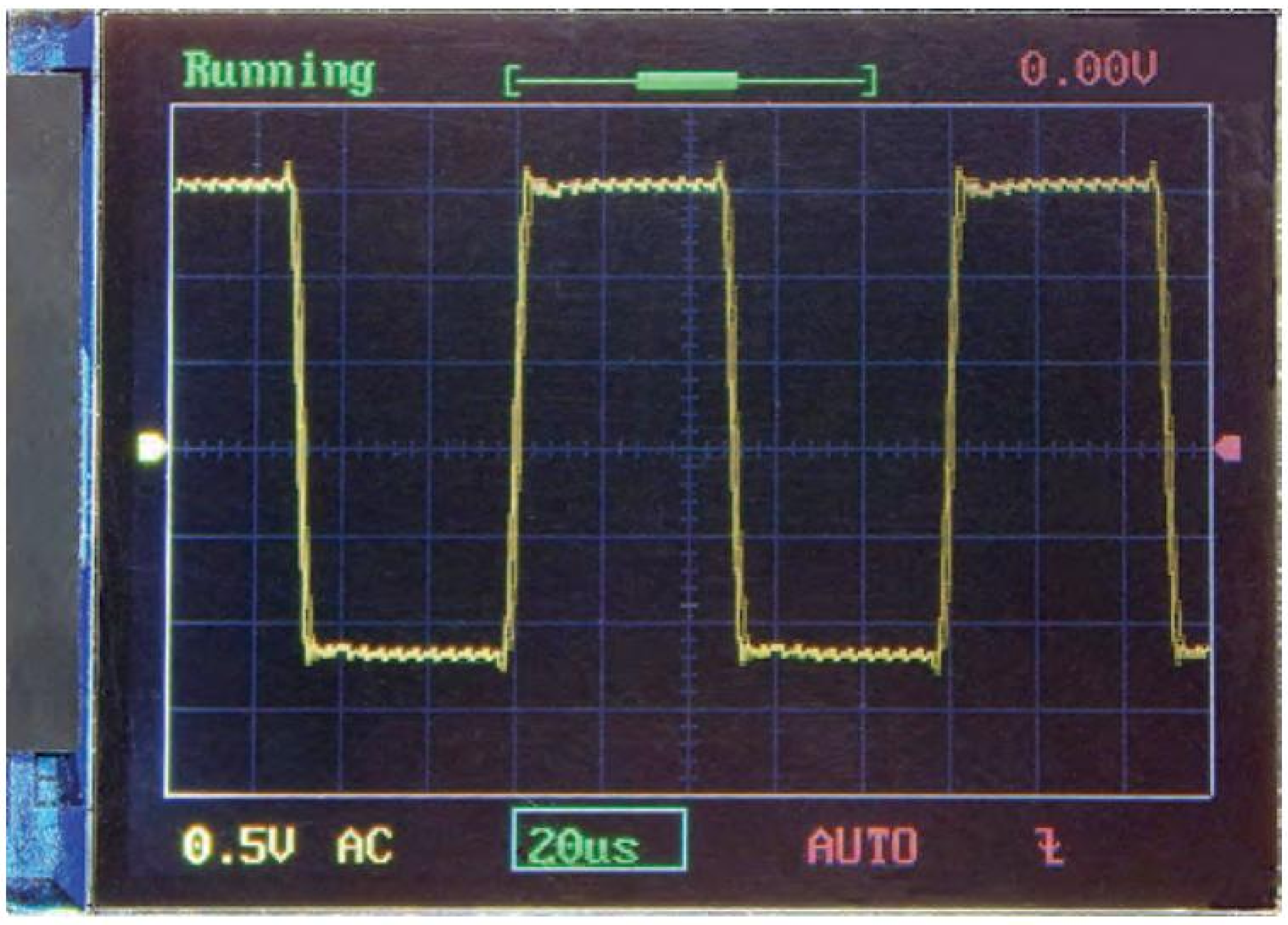
Since the PCB assembly is so straightforward, you might expect the case would also come with clear instructions and that it would be easy to put together. But it isn't quite that straightforward. All you actually get are the nine laser-cut pieces of acrylic sheet plus a small plastic bag with some control switch extension pieces moulded in red plastic, and some M2.5 and M3 machine screws and nuts.

The acrylic pieces are covered in protective paper sheet on both sides but there is no assembly information.

Perhaps this is supposed to be self-evident, but after a while I gave up and went to the Banggood website to look for clues. I found several YouTube clips showing the assembly of the case. (See **www.youtube.com/watch?v=9vtHZP2=KAU**).

By playing the clip quite a few times – and pausing here and there as well – I was finally able to get the sequence right. (There are several other clips – simply go to YouTube and search for 'DSO138 case'.)

There was one further little complication with regard to the red plastic control switch extension pieces. These allow you to operate the small slider switches and pushbuttons on the PCB when it's mounted in the case.


Running
0.00V
0.5V AC
20us
AUTO

A close-up of the LCD screen before mounting in the case, showing a 10kHz square wave. No-one is pretending that it's perfect – obviously not as good as you'd find on a multi-hundred (or multi-thousand!) pound DSO . . . but for well under £20 the DSO138's performance is surprisingly good!

The extension pieces for the three slider switches were easy to identify, because they are T-shaped with a small locating slot moulded into the top centre of the 'T' (which actually becomes the bottom of the extension). But the extension pieces for the five pushbuttons were harder to work out.

They seemed to be I-shaped with a bump at both ends, and there seemed to be only three of them in the kit instead of the five I was expecting.

Had someone made a mistake? No, because I eventually realised that each 'I' piece was actually two small 'T' pieces moulded together with a fine central groove which allowed them to be snapped apart. After this I didn't have any problems, and it all went together nicely as shown in the photo.

Performance

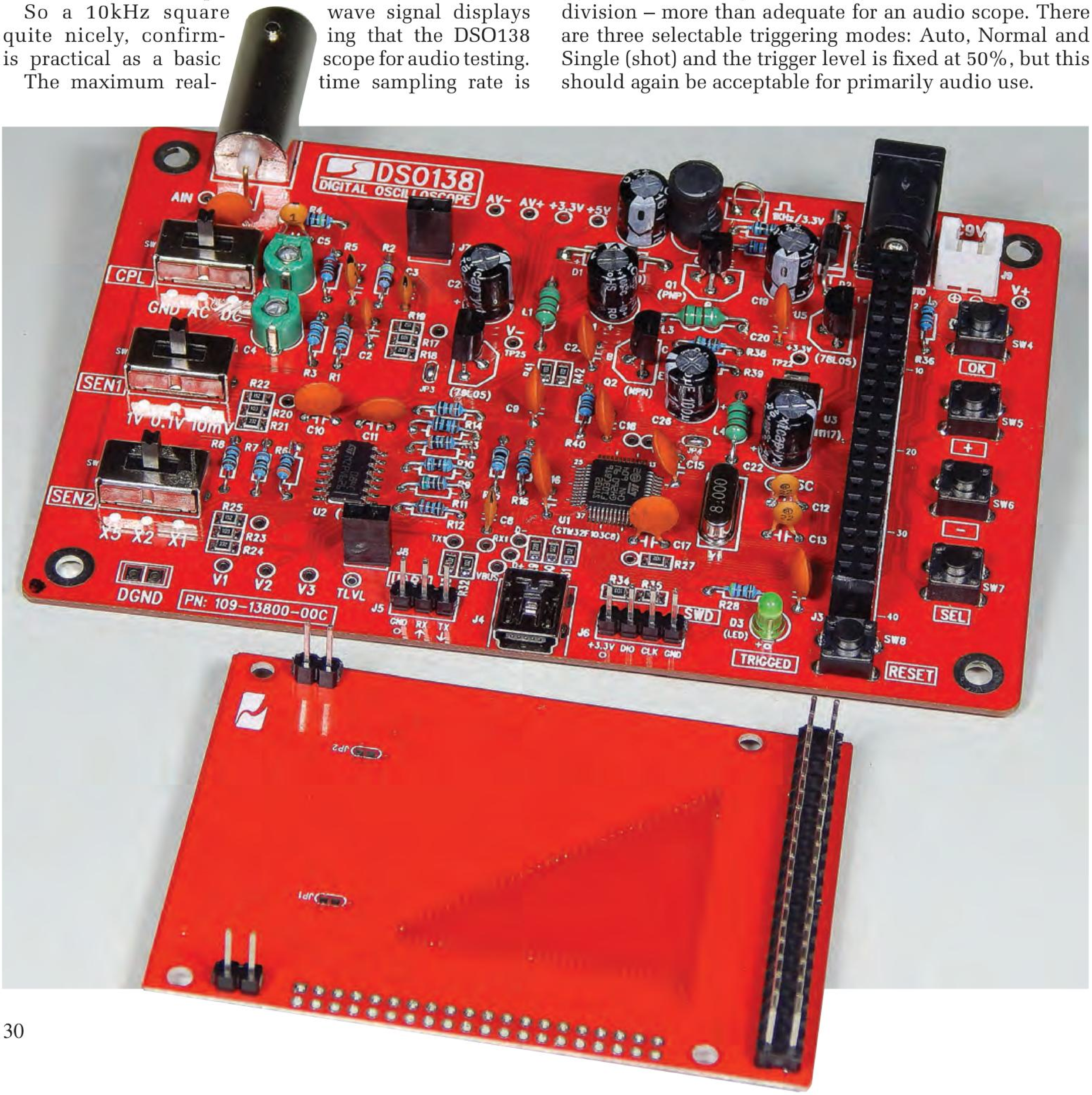
Putting the completed DSO138 through its paces was a pleasant surprise. The analogue bandwidth measured –1dB at 150kHz, –2dB at 175kHz and –3dB at very close to the 200kHz stated in the specification.

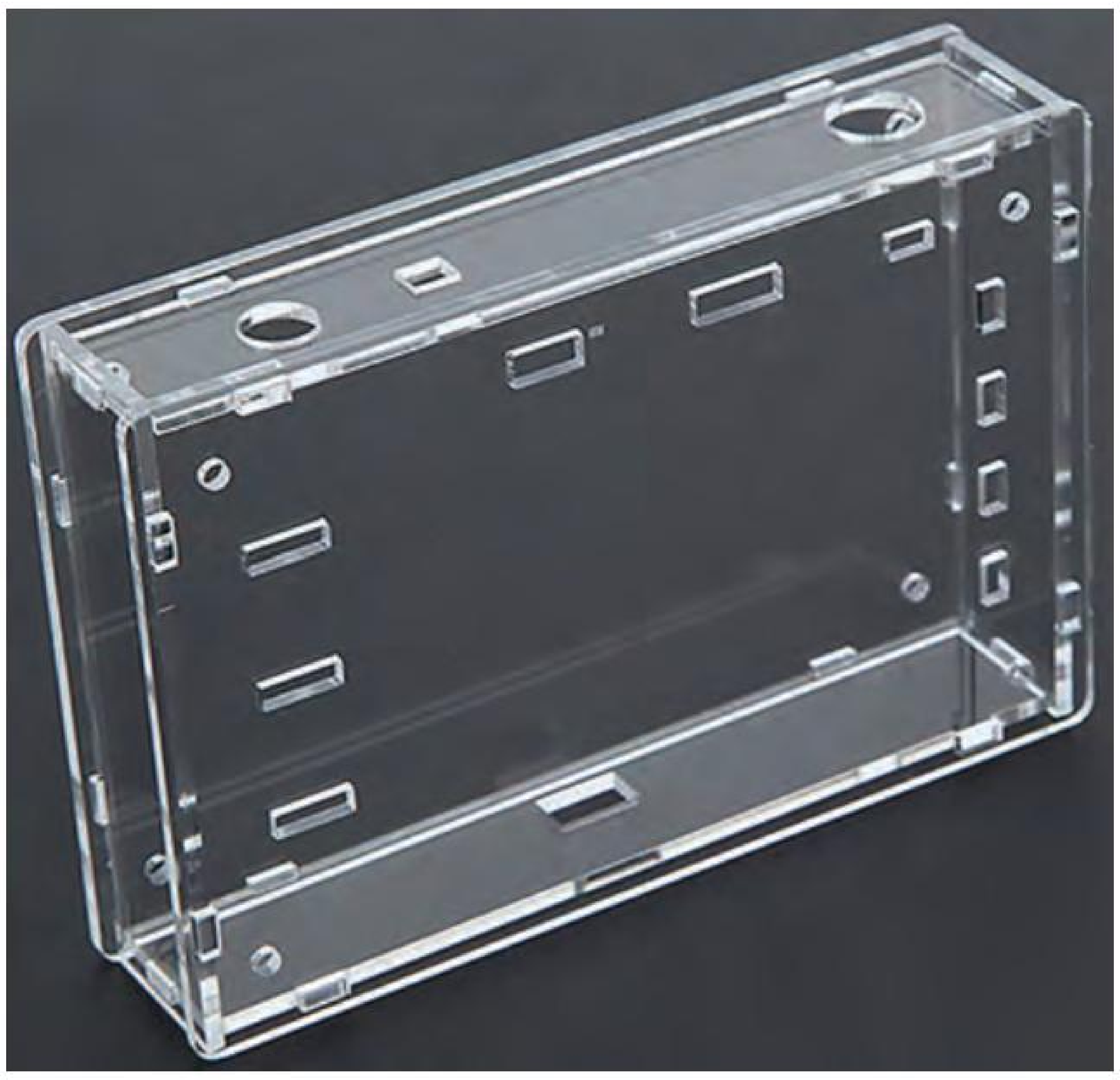
So a 10kHz square wave signal displays quite nicely, confirming that the DSO138 is practical as a basic scope for audio testing.

The maximum real-time sampling rate is 1MS/s, with a vertical resolution of 12 bits and a record length of 1024 points. The input sensitivity range spans from 5V/division down to 10mV/division, while the input impedance is 1MΩ shunted by approximately 20pF – pretty much standard.

The rated maximum input voltage is 50V peak (100V peak-to-peak), so for measurements in higher-voltage circuits you'd need to use it with a 10:1 divider probe.

The timebase range is from 10μs/division down to 500s/division – more than adequate for an audio scope. There are three selectable triggering modes: Auto, Normal and Single (shot) and the trigger level is fixed at 50%, but this should again be acceptable for primarily audio use.


DSO138
DIGITAL OSCILLOSCOPE
AIN
AV− AV+ +3.3V +5V
1KHz/3.3V
9V
J9
V+
CPL
GND AC DC
SEN1
1V 0.1V 10mV
SEN2
X5 X2 X1
DGND
PN: 109-13800-00C
V1 V2 V3 TLVL
J5
GND RX TX
J4
J6
+3.3V DIO CLK GND
SWD
D3 (LED)
TRIGGED
U1 (STM32F103C8)
U3 (1117)
U5 (78L05)
Q1 (PNP)
Q2 (NPN)
8.000
SW4
OK
SW5
+
SW6
−
SW7
SEL
SW8
RESET
JP2
JP1



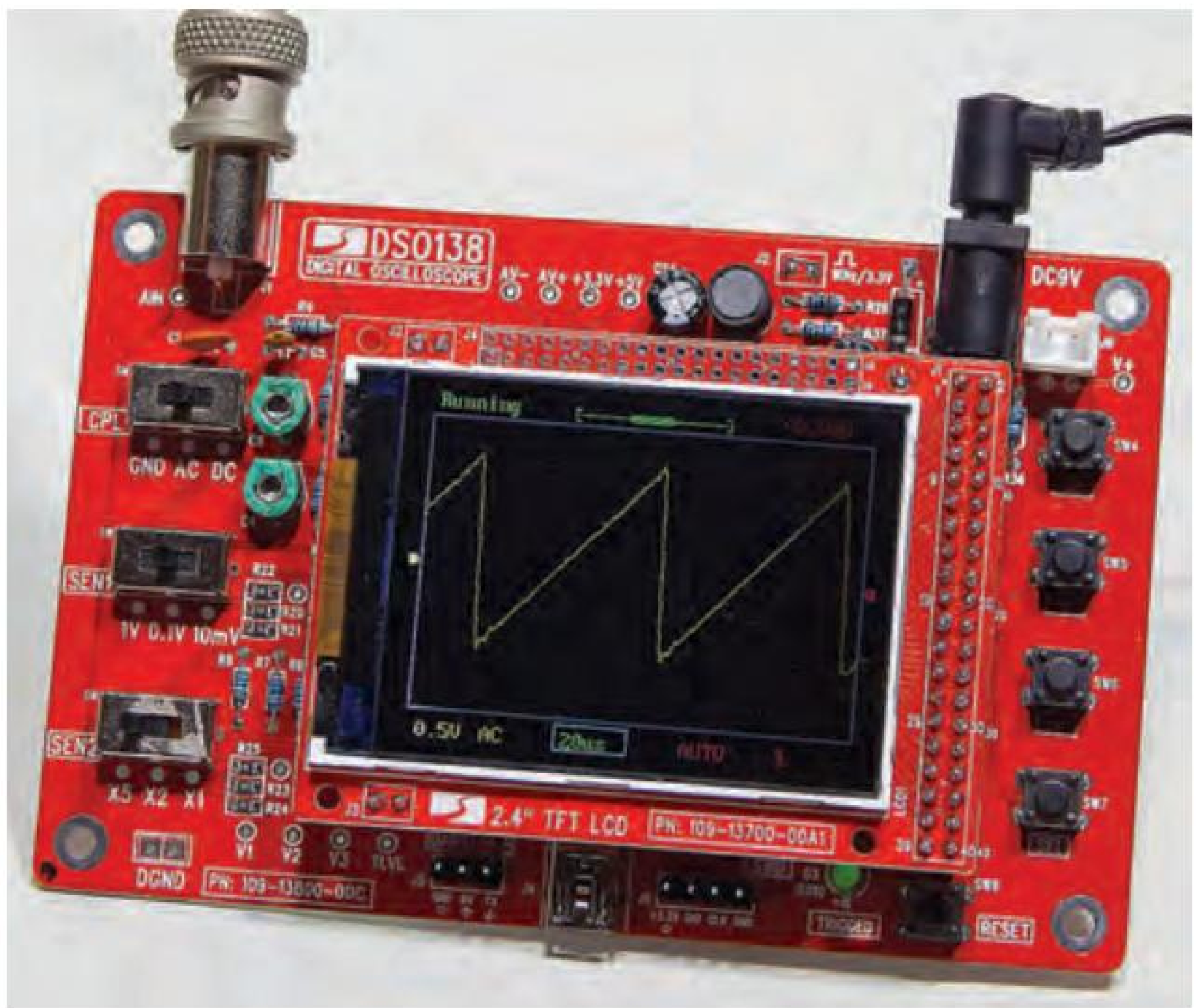
Taken from Banggood's website, this shows the assembled case without any content, to show you how all the outer pieces of the box fit together.

Incidentally, I don't know if you'll be able to see this in the photos, but although the active part of the DSO138's 2.4-inch TFT LCD screen is fairly small (49 × 37mm), its resolution of 320 × 240 pixels with 262,144 colours results in a very sharp and well-defined display.

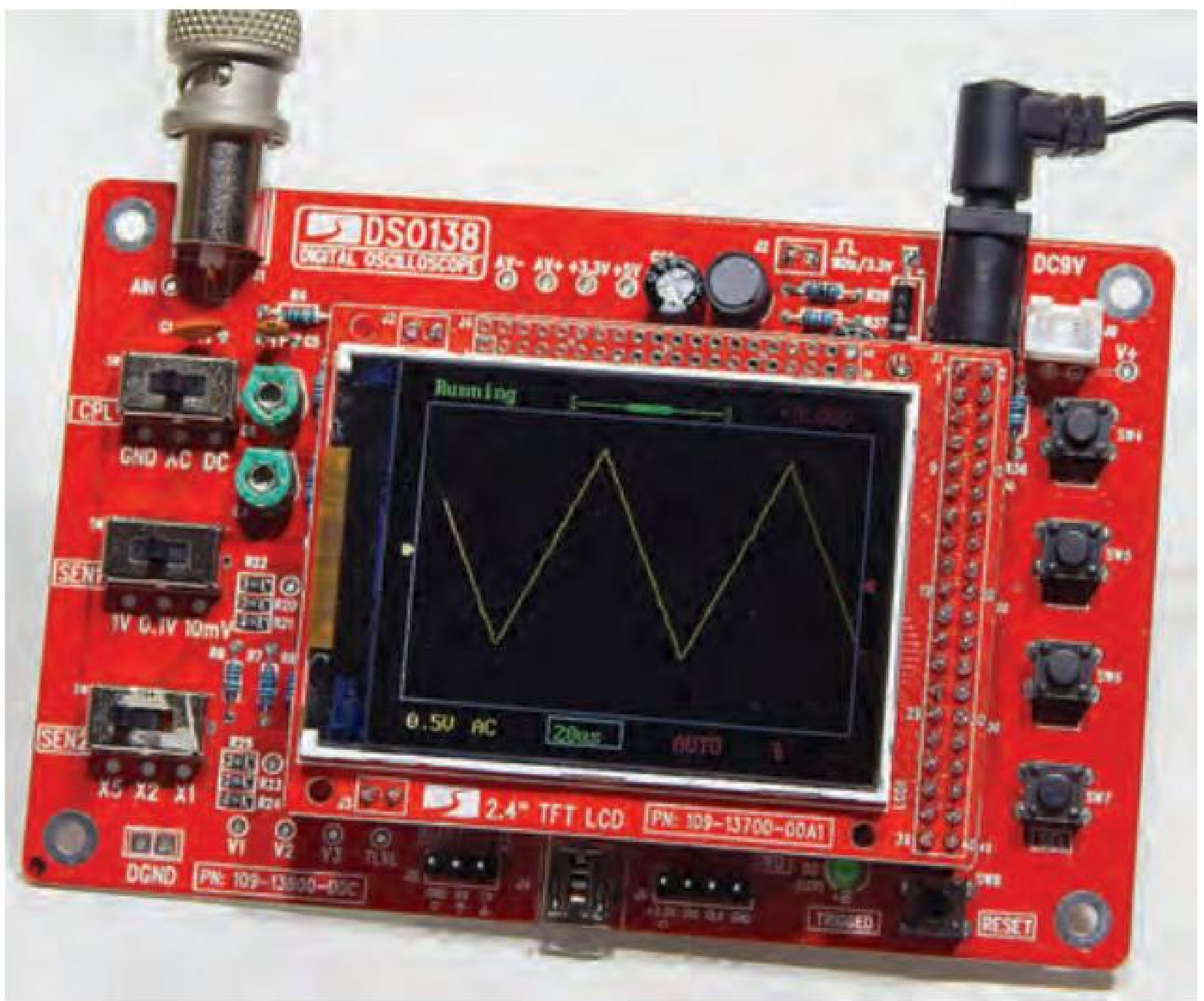
I should also mention that the DSO138 is designed to run from a nominal 9V DC supply, but since its current drain is around 120mA, it isn't feasible to use a standard 216-type 9V alkaline battery. The simplest options are a 9V DC regulated plugpack or a pack of six AA or C size alkaline cells in series.

However, JYE Tech also have a very small step-up DC-DC converter module, the JYE140, which can be used to provide the DSO138 with 9V DC derived from a standard low-cost 5V DC plugpack or Li-Ion battery. Based on an MC34063 converter chip, the JYE140 has an output current capability of 150mA, an output ripple of around 100mV at full loading and its output can be plugged directly into the rear of the DSO138.

If you are interested in this option, the JYE140 converter can also be ordered online from the Banggood website for £2.89 (product ID 1000089), again with free delivery to your door. At that price, you certainly wouldn't bother to build it yourself!



(Above) here the DSO138 is displaying a 10kHz sawtooth wave... (below) it's a 10kHz triangle wave.



The final verdict

Overall, I'm happy to give the JYE Tech/Banggood DSO138 scope kit a rating of 4.5 stars out of five. The electronics side of the kit is easy to put together and seems well-designed.

Features like the inbuilt 1kHz square wave probe calibration signal output and the self-test function testify to this, and makes the kit well above average given its low price.

The DIY acrylic box is quite good too, once you have figured out how to put it together. And the performance of the completed DSO138 is quite good enough to qualify it as a useful tool for audio testing and troubleshooting.

The DSO138 kit represents outstanding value for money. It's almost worth buying just for the fun of putting it together and trying it out, even if you're going to give it away!

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POWER SUPPLY FOR BATTERY-OPERATED VALVE RADIOS

By Ian Robertson

Batteries for vintage radios can be hard to get and expensive. This power supply is a neat solution.

Apart from some portable models, most battery-operated valve radios were intended for use on farms and in remote regions where mains power was not available.

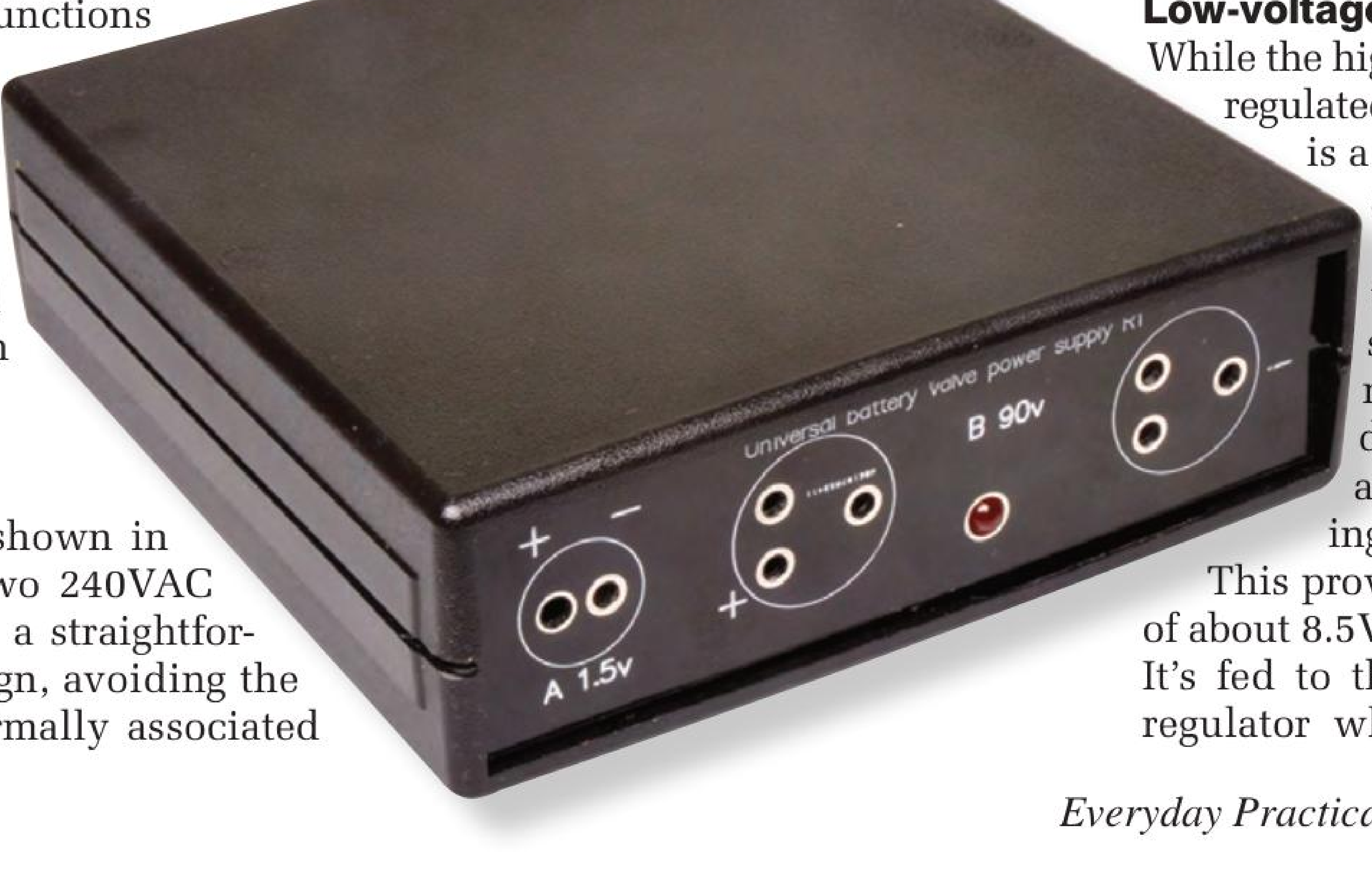
Those sets are quite collectible today, but most vintage radio enthusiasts power them from a variety of makeshift power supplies, some of which are of doubtful safety.

This universal power supply is easy to build and could be installed inside the battery compartment of some radios. If there isn't enough space, it could be connected with two cables; one for the 1.5V or 2V filaments and one for the 90V or 135V B+ supply.

Of course, quite a few battery-powered radios used vibrators to produce the B+ supply and if you have one of these radios with a defective vibrator section, this power supply could also provide a work-around, either temporary or permanent.

The supply uses three PCBs connected together and is designed to fit in a standard plastic instrument case. One of the PCBs doubles as the front panel, while an additional (fourth) PCB is unconnected but functions as the rear panel.

There is no wiring between the three PCBs. Instead, they are butted at right-angles and soldered together, as shown in the photos.



Circuit details

The full circuit is shown in Fig.1. It employs two 240VAC transformers and is a straightforward analogue design, avoiding the RF interference normally associated with more efficient switchmode power supplies.

The top section of the circuit is for the low-voltage supplies and employs an LM338 or LM317T adjustable regulator. The example shown in the photos is fitted with the LM338 regulator, which comes in a TO-3 metal case.

The lower section of the circuit is for the high-voltage B+ supplies. Let's describe the lower section first.

It employs a mains transformer with two 15V windings connected in series to provide 30VAC. This is connected to diodes D1 and D2 and the two associated 220µF capacitors which function as a conventional full-wave voltage multiplier.

In effect, diodes D1 and D2 can be regarded as two half-wave rectifiers stacked together to provide an output voltage equal to twice the peak voltage from the transformer winding.

For a sinewave of 35V RMS, the peak voltage will be V_{AC} × 1.414, so the voltage doubler output will be 85V, neglecting the voltage drop across D1 and D2.

However, in this circuit the transformer is likely to be quite lightly loaded and so the peak voltage will probably be around 48V, and so the output will be more than 90V DC.

The actual voltage will depend on the incoming mains voltage and the load presented by the radio's circuit. So that accounts for the voltage between the B+90V and B– terminals of CON2.

Diodes D3 and D4, with their two associated 220µF capacitors function as a half-wave diode pump rectifier. Their output is stacked on that of the full-wave voltage doubler (D1 and D2), to give a higher total output at the B+135V and B– terminals of CON1.

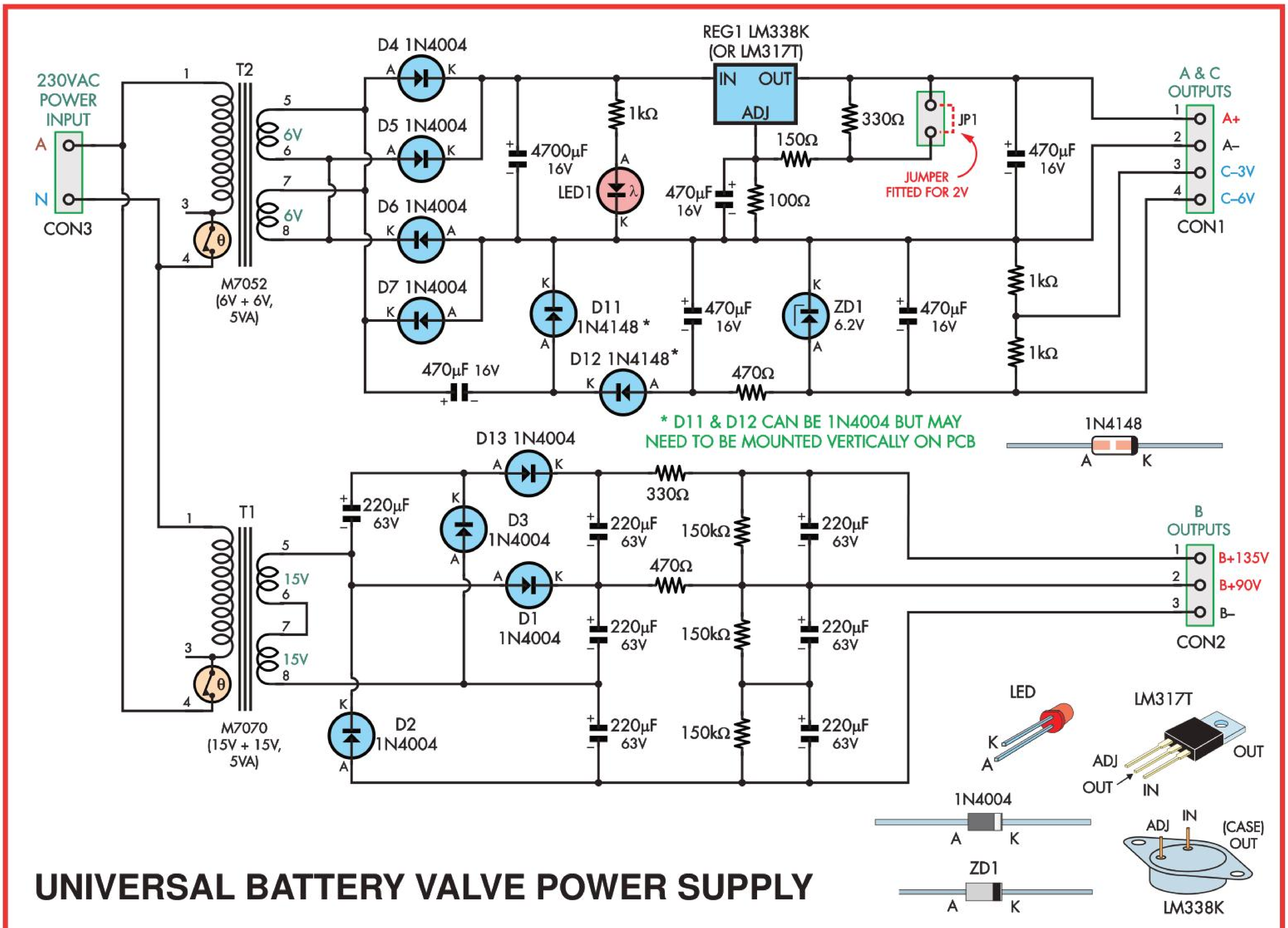
This is likely to be between 130V and 145V, depending on mains voltage and circuit loading, as before.

The 330Ω resistor and three stacked 220µF capacitors provide extra hum filtering for the output, while the parallel 150kΩ resistors across each 220µF capacitor are there to equalise the voltage across them. So each 220µF capacitor should have one-third of the output voltage across it.

Low-voltage regulator circuit

While the high-voltage outputs are unregulated, the low-voltage circuit is a combination of regulated and unregulated supplies. It uses a second mains transformer with two 6V secondary windings connected in parallel to feed diodes D4-D7 connected as a bridge rectifier feeding a 4700µF 16V capacitor.

This provides a filtered DC output of about 8.5V (depending on loading). It's fed to the adjustable 3-terminal regulator which has three resistors


230VAC POWER INPUT
A
N
CON3
T2
M7052 (6V + 6V, 5VA)
6V
6V
T1
M7070 (15V + 15V, 5VA)
15V
15V
D4 1N4004
D5 1N4004
D6 1N4004
D7 1N4004
4700µF 16V
1kΩ
LED1
λ
REG1 LM338K (OR LM317T)
IN
OUT
ADJ
470µF 16V
150Ω
100Ω
330Ω
JP1
JUMPER FITTED FOR 2V
470µF 16V
1kΩ
1kΩ
A & C OUTPUTS
A+
A–
C–3V
C–6V
CON1
D11 1N4148 *
D12 1N4148*
470µF 16V
470µF 16V
ZD1 6.2V
470µF 16V
470Ω
* D11 & D12 CAN BE 1N4004 BUT MAY NEED TO BE MOUNTED VERTICALLY ON PCB
1N4148
D13 1N4004
D3 1N4004
D1 1N4004
D2 1N4004
220µF 63V
330Ω
470Ω
150kΩ
150kΩ
150kΩ
B OUTPUTS
B+135V
B+90V
B–
CON2
LED
K
A
LM317T
ADJ
OUT
IN
1N4004
ZD1
LM338K
(CASE) OUT

UNIVERSAL BATTERY VALVE POWER SUPPLY

The circuit consists of two independent power supplies, with various voltages available to suit a wide range of battery-operated valve receivers. Provision is made on the PCB for either a TO-3 or a TO-220-case regulator.

connected to its ADJ terminal set to give a regulated output of 1.5V.

If you want a regulated output of 2V, the shorting link must be installed across JP1. Extra filtering of the regulator's output is provided by the 470µF capacitor connected across terminals A+ and A– of CON1.

Negative outputs

Battery-operated valve radios often had C batteries to provide a negative grid voltage for the valves, and this could be –3V, –4.5V or –6V.

These negative rails are provided by the diode pump circuit comprising diodes D11 and D12, in conjunction with two 470µF 16V capacitors.

The resulting filtered DC is fed to zener diode ZD1 via a 470Ω resistor and bypassed by an additional 470µF capacitor. A voltage divider comprising two 1kΩ resistors then provides outputs of 3V and 6V at the C–3V and C–6V terminals of CON1.

If you require a C– rail of 4.5V, then ZD1 should be a 4.7V zener diode.

Construction

The power supply is primarily constructed on one main PCB measuring 55 × 110mm.

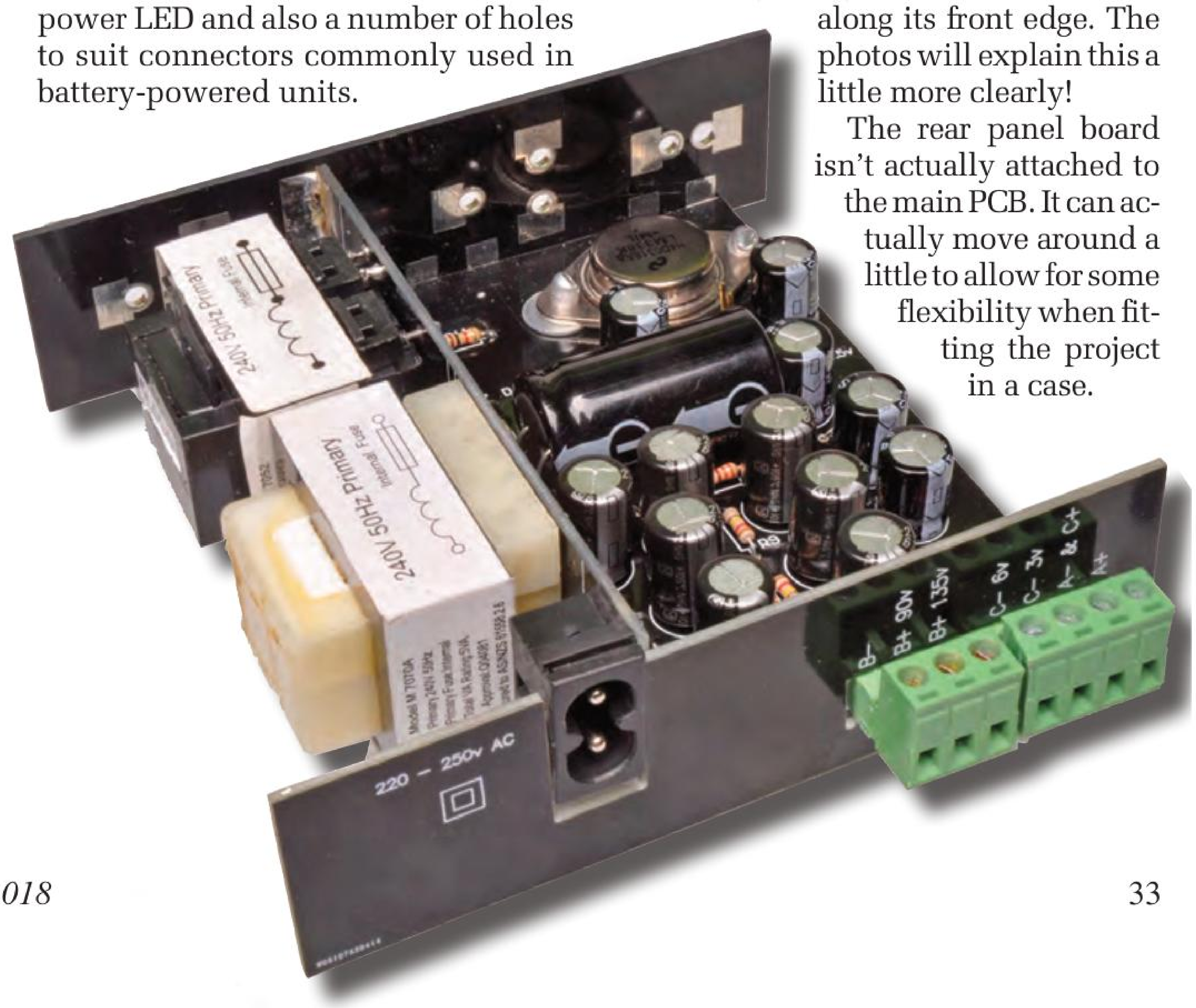
There are also three 'supplementary' PCBs, one of which mounts the two power transformers and the 'figure-8' mains input socket. They are 110 × 33mm. Two other PCBs, 122 × 33mm, form the front and rear panels of the project. (The set of four PCBs is available from from the *EPE* PCB Service).

The front PCB has holes for the power LED and also a number of holes to suit connectors commonly used in battery-powered units.

The power transformer board is soldered at right angles to one edge of the main PCB via the use of the secondary windings pins (eight in all), which pass through the transformer board and solder to large pads provided on the edge of the main board.

Similarly, the front panel board solders at right angles to the main board along its front edge. The photos will explain this a little more clearly!

The rear panel board isn't actually attached to the main PCB. It can actually move around a little to allow for some flexibility when fitting the project in a case.


240V 50Hz Primary
240V 50Hz Primary
220 – 250v AC
B–
B+ 90V
B+ 135V
C– 6v
C– 3v
A– & C+
A+

However, and this is most important, the three and four-pin DC output sockets must be passed through this panel **before** they are soldered in place – we'll get back to this a little later.

One other point which we'll cover later but should be highlighted up front is that the 230VAC mains connections to the transformers, along with the mains input socket, all have their pins exposed ready to trap the unwary.

After completion, we covered ours with liberal coating of silicone sealant for absolute safety.

Begin construction by soldering in the 12 resistors – check their values with a DMM. After the resistors, solder in the nine 1N4004 diodes, taking care with their polarity.

The original project used 1N4148 diodes in two places, but we'd prefer to see 1N4004 used instead, if only to give a higher margin for inrush current.

However, the PCB pattern may not allow for the slightly longer 1N4004s so if you elect to use these, they may need to be mounted vertically (obviously maintaining the correct polarity).

The only other diode is zener ZD1 – again, of course, it is polarised.

All other components are also polarised – the 220µF and 470µF vertical capacitors (don't mix 'em up!) and the main 4700µF filter capacitor which, as you will note from our photos, is a vertical type but which lies horizontal on the board. As well as soldering it in place, a dob of silicone sealant underneath will help stop any movement.

2-pin header JP1 is the last small component to solder in (fairly obviously, it's not polarised!).

All that's left is the LED and the TO-3 regulator. Leave the LED for the moment but solder in the regulator, which can only go in one way. Note that it is spaced above the board by a washer at each end, held in place by its mounting screws/nuts.

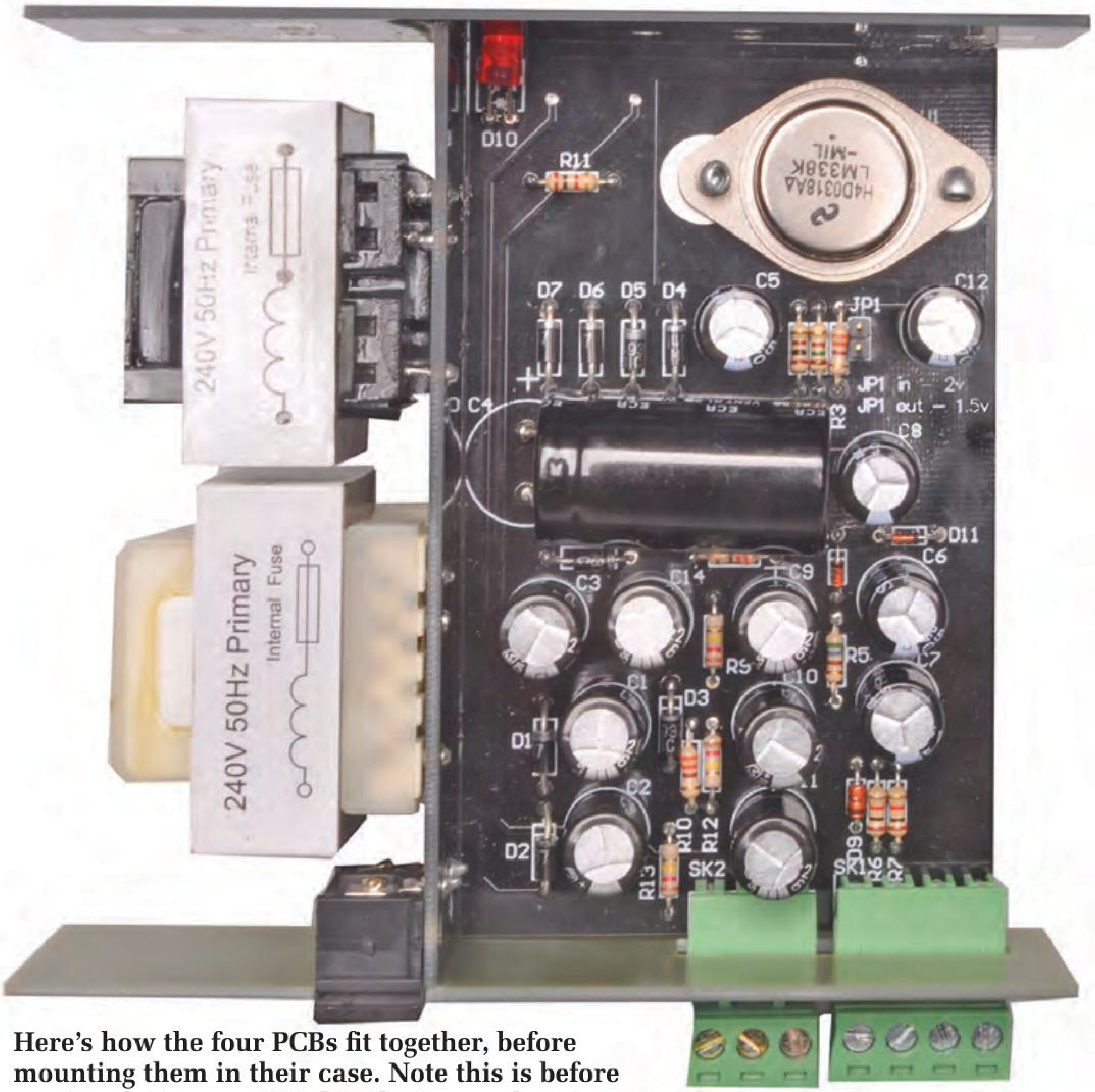
This allows a little air circulation under the case, assisting cooling and also avoids metal-to-glass stressing which might otherwise occur.

Incidentally, it is possible to use an LM317T TO-220 regulator instead of the now-harder-to-get LM338 TO-3 device shown in our photographs.

The TO-220 'ADJ' and 'IN' pins mount to the same two holes as the TO-3. A hole has been provided on the PCB for the 'OUT' pin as well. If you use an LM317T, a small 'U' heatsink will also need to be inserted under the regulator.

Place the LED in its holes (anode, the longer lead, closer to the edge of the board) but don't solder it in yet.

Also, don't fit the DC output terminals (CON1 and CON2) yet – these have to be passed through the rear panel first.



Here's how the four PCBs fit together, before mounting them in their case. Note this is before any insulation was fitted to the exposed mains.

Transformer board

The two mains transformers, along with the 2-pin mains socket, mount on the transformer board. T1, the 2 × 15VAC transformer, is closest to the mains socket.

Solder the mains socket in first, then solder the primaries of both transformers, but leave the secondaries for the moment – they're used to solder the transformer board to the main board.

Only after soldering the two boards together should you trim the primary pins (eliminating the possibility of trimming the wrong ones).

Soldering the vertical boards

As we mentioned earlier, two of the three smaller boards are soldered at right angles to the main board. It's lighter, so solder the front panel board on first by lining up the rectangular pads on it with the matching rectangular pads on the main board, with the front panel about 2mm down from the main board (see photo). Tack one pad first to ensure the panel is straight with respect to the main board, then solder all four pads so the panel is secured.

Repeat for the transformer board. It is soldered to the main board in the same manner as the front panel (ie, 2mm down from the underside of the main board); the difference, of course, is that it is along the side of the main board.

The bottom edges of both the front panel and the transformer board should line up.

There is one more solder joint to be made, that is to join the transformer board and the front panel via the long pads on each, which, if you've done everything correctly, should line up. You'll need a pretty fine iron bit to get in between T2 and the board.

Construction is now almost finished. All that remains is to poke LED1 through the front panel and solder it to the main board, then to fit CON1 and CON2 and the rear panel.

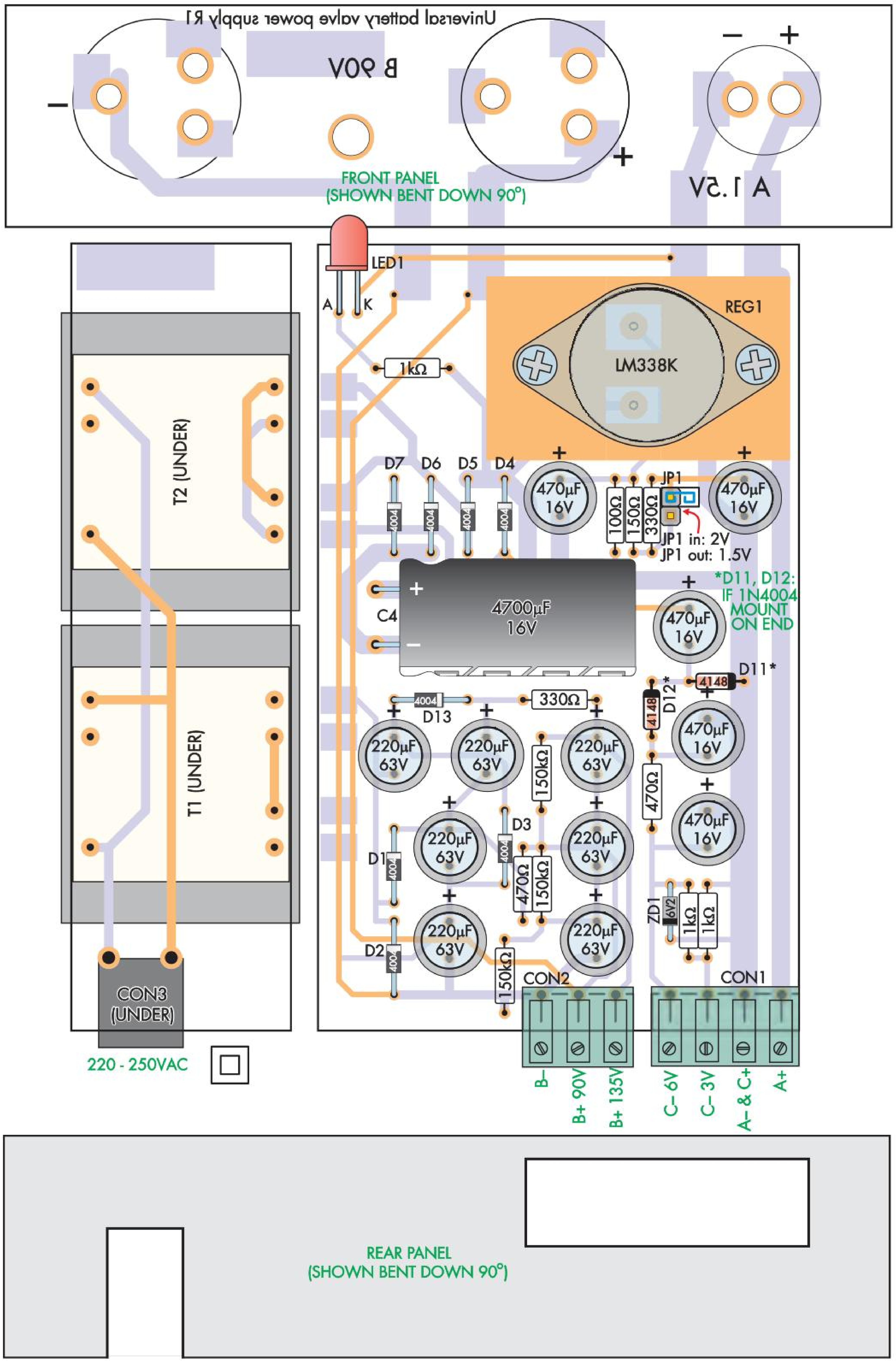
Pass both of these terminal blocks through the panel (they're a loose fit) then into the main board. The four-way socket goes to the edge of the main board. Solder both blocks in place.

At the same time, slip the rear panel over the mains socket and now you're all done.

Mounting in its box

Because there are relatively high DC voltages present (not to mention 230VAC mains) we would always prefer to see the assembled boards mounted in their case.

The PacTec CM6-150 box we used (available from **mouser.co.uk**) is almost perfect – but that 'almost' bit causes a few problems.


Universal battery valve power supply R1
B 90V
A 1.5V
FRONT PANEL
(SHOWN BENT DOWN 90°)
LED1
A
K
1kΩ
REG1
LM338K
T2 (UNDER)
T1 (UNDER)
D7
D6
D5
D4
4004
470µF 16V
100Ω
150Ω
330Ω
JP1
JP1 in: 2V
JP1 out: 1.5V
*D11, D12: IF 1N4004 MOUNT ON END
C4
4700µF 16V
D11*
4148
D12*
D13
330Ω
220µF 63V
150kΩ
470Ω
D3
D1
D2
ZD1
6V2
1kΩ
CON2
CON1
CON3 (UNDER)
220 - 250VAC
B–
B+ 90V
B+ 135V
C– 6V
C– 3V
A– & C+
A+
REAR PANEL
(SHOWN BENT DOWN 90°)

The component overlay also shows the transformer board and the front and rear panels. Output can be taken from the screw terminals on the rear panel or from suitable sockets on the front panel, which match typical connectors used in battery valve radios. Do not neglect to insulate all the 'bitey bits' on the PCB.

Parts List – Battery Valve Power Supply

- 1 main PCB, 55 × 110mm, coded 18108171*
- 1 transformer PCB, 110 × 33mm, coded 18108172*
- 1 front panel PCB, 122 × 33mm, coded 18108173*
- 1 rear panel PCB, 122 × 33mm, coded 18108174*
- 1 2-part plastic case, 125 × 130 × 40mm (see text)
- 1 15V + 15V mains transformer (T1)
- 1 6V + 6V mains transformer (T1)
- 1 PCB-mount figure-8 mains socket (CON3)
- 1 mains lead with figure-8 plug
- 1 2-pin header base, PCB-mounting
- 1 2-pin header
- 1 4-pin screw terminal block, PCB- mounting (CON1)
- 1 3-pin screw terminal block, PCB- mounting (CON2)
- 2 M3 × 6mm screws, nuts and washers
- 2 M3 washers

Semiconductors

- 1 LM338K TO-3 regulator (or LM317T – see text)
- 8 1N4004 silicon diodes
- 2 1N4148 silicon diodes (see text)
- 1 6.2V 400mW zener diode
- 1 5mm red LED

Capacitors

- 7 220µF 63V PCB electrolytics
- 5 470µF 63V PCB electrolytics
- 1 4700µF 16V PCB electrolytic

Resistors

- 1 100Ω
- 2 470Ω
- 1 150Ω
- 3 1kΩ
- 2 330Ω
- 3 150kΩ

* A set of the four PCBs (including the two panels) is available from the *EPE PCB Service* (**epemag.com**). All other parts are readily obtainable from your normal parts suppliers.

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The dilemma is that the box is not quite deep enough to fit the transformers. It's about 2mm too shallow. There are also a few mounting pillars which we don't use and, in fact, interfere with the mounting.

In our prototype, this was overcome by grinding off the mounting points with a Dremel grinder (or similar) – easy – and then removing about 2mm thickness from the inside of the case above where the transformers sit – same tool, not quite so easy!

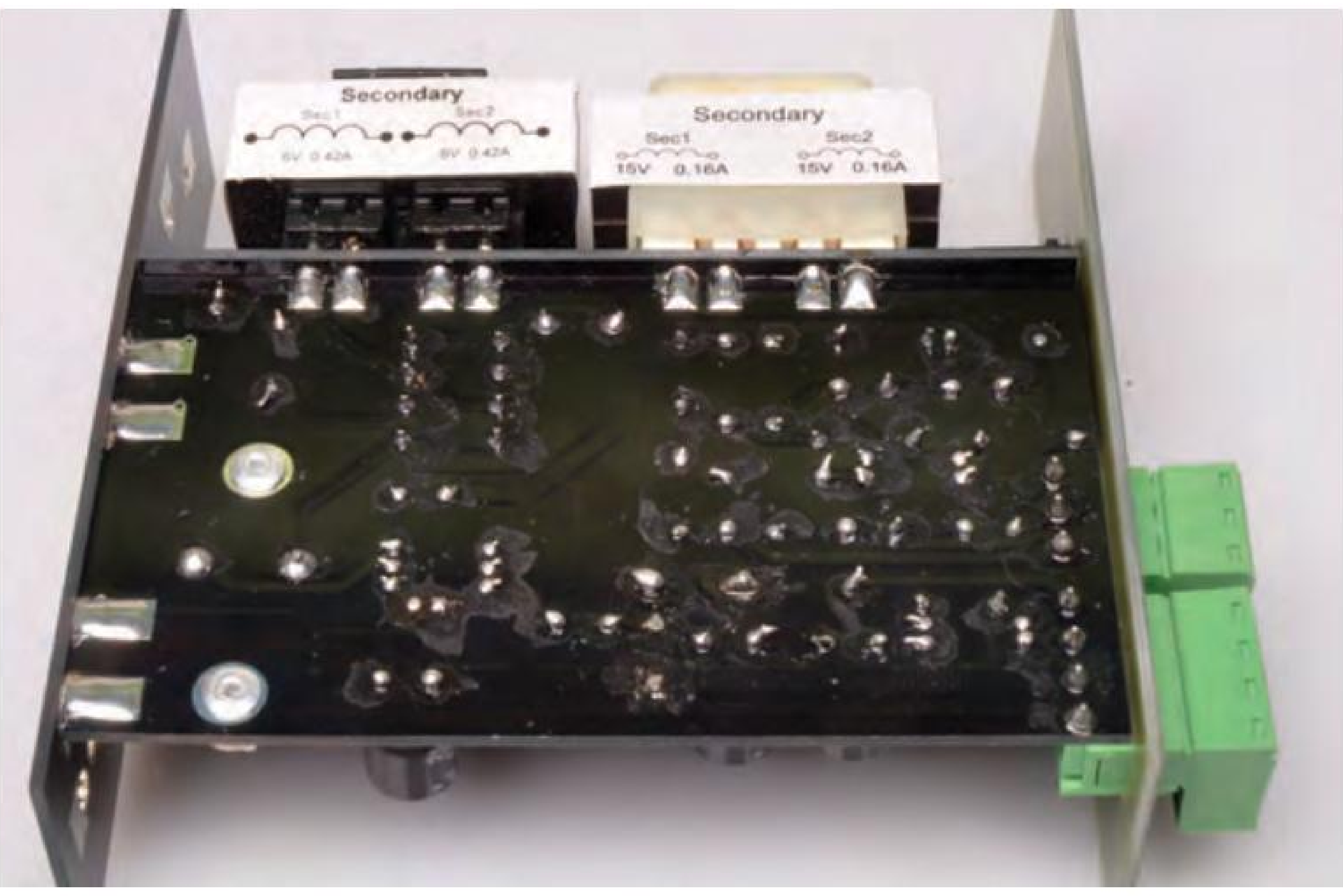
The photos show how we achieved this. When completed, it's a tight fit, but it's a fit!

The board assembly can be mounted so the front panel is flush with the front of the case, which puts the rear panel inset about 13mm (that's the way the mounting guides are moulded in the case) or vice-versa; ie, inset the front panel 13mm and have the rear panel flush. It's your choice.

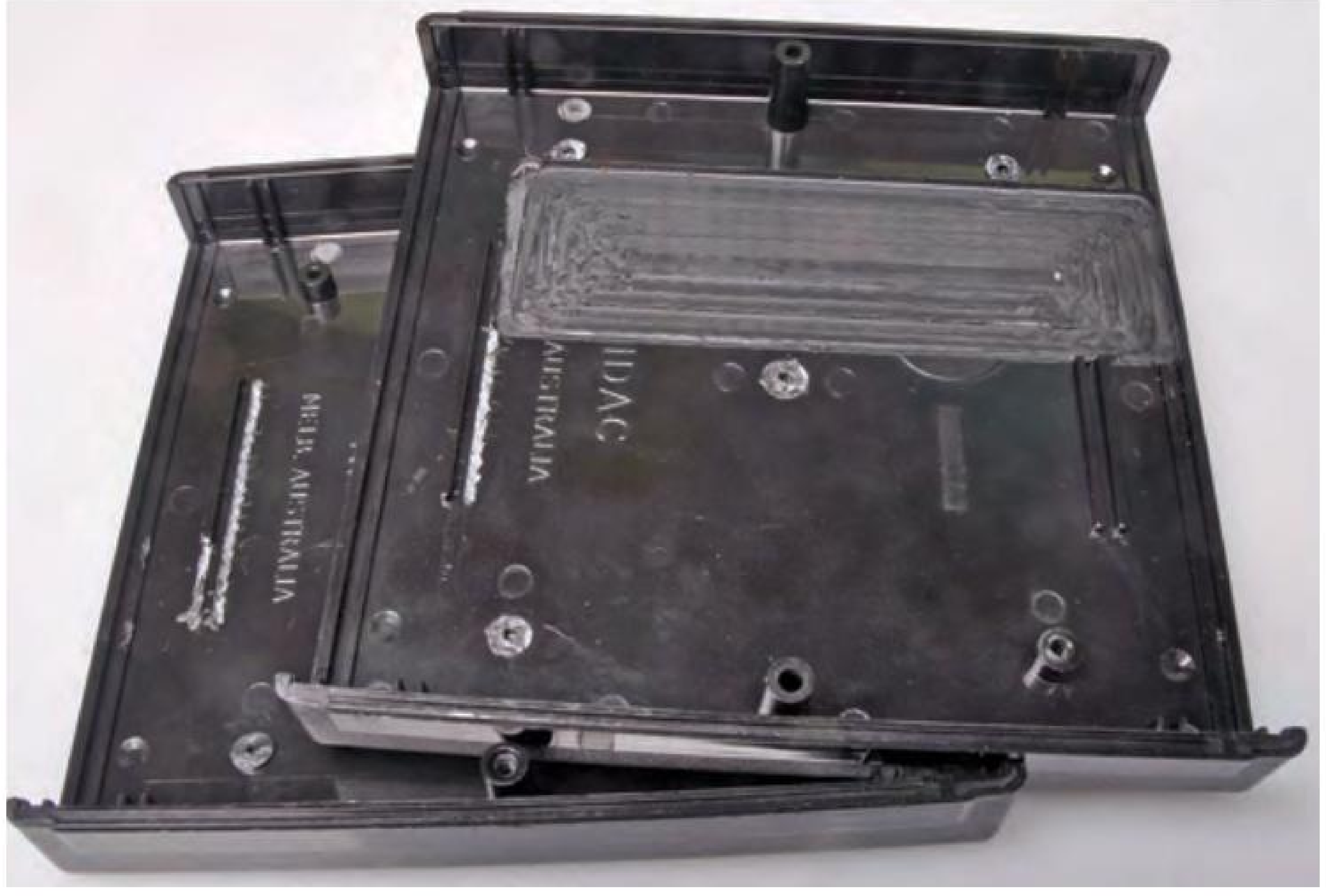
Testing

First of all, beware the mains-carrying pads on the transformer board – you should only coat these after testing.

1. Connect a meter to the B+ (135V) and B– connections using the 3-way pluggable screw terminals.
2. Connect power – LED should light.
3. You should measure close to 145V. If not, switch off immediately and check your work.
4. If all is well, check the A+ and A–/C+ terminals. You should see very



The underside of the PCB assembly showing how the main board, transformer board and front panel are soldered to each other. The rear panel (right) is not secured at all but is held loosely in place by the two output sockets. The main board is soldered 2mm down from the edges of the transformer board and panel.



'Surgery' required on the case halves to allow the transformers and the assembly to fit inside the case. The lighter grey area is where we ground out about half the case thickness with a Dremel for the transformer clearance; other areas are where the mounting pillars were removed (none of these are used).

close to 1.5V with JP1 not shunted. Shorting JP1 should change the A voltage to 2V.

5. The A (filament) voltages will measure the same irrespective of load.
6. Check the C voltages – you should see close to 6V and 3V.

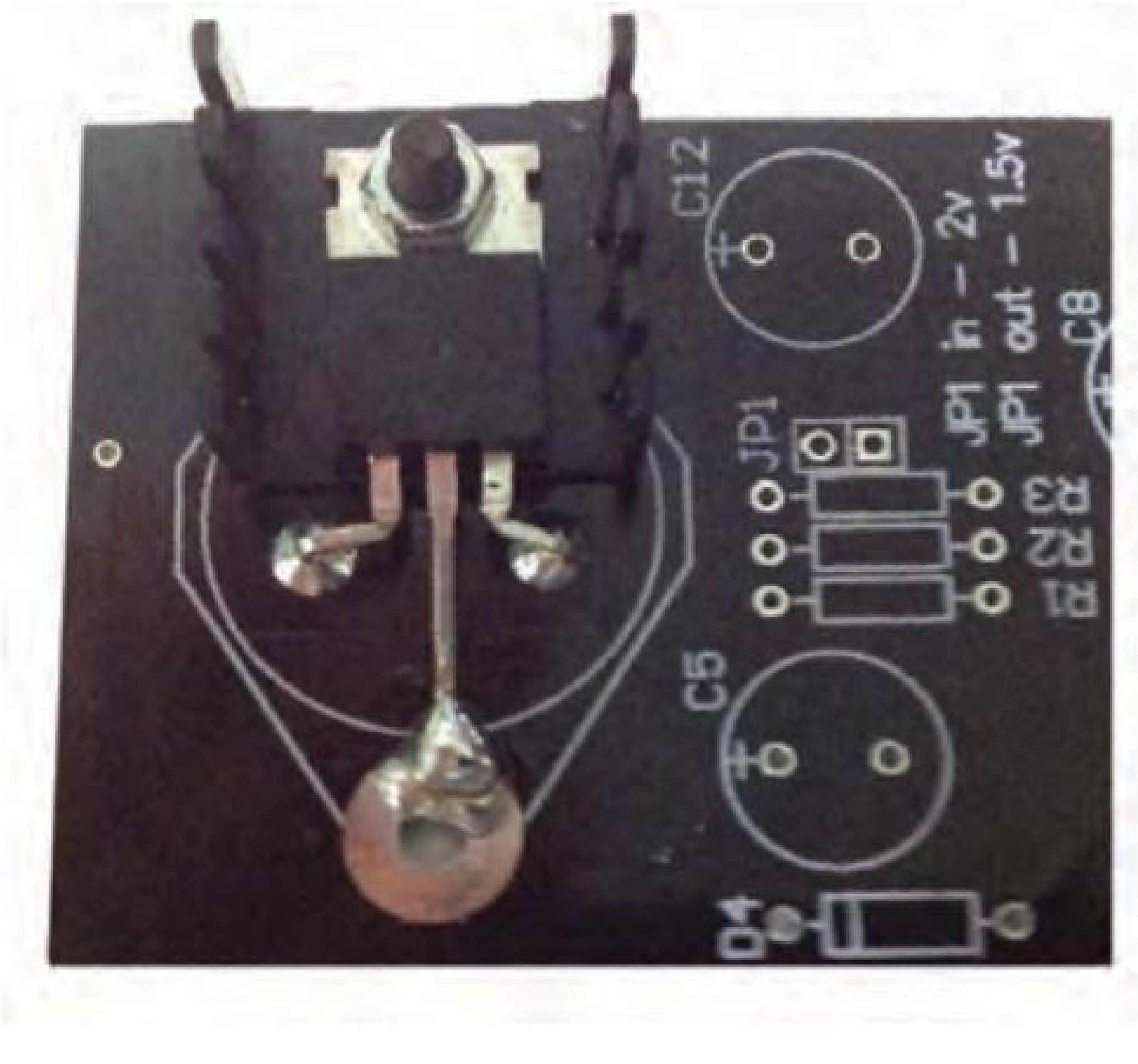
If all this checks out, you can disconnect AC power and only then apply the silicone sealant to the exposed mains points on the transformer PCB, then fit the top cover and your power supply is ready for use!

Modifications

Here are some simple modifications you can make to adapt the power supply for less common radios.

45V tap

1. Add a 470Ω resistor between the anode of D3 and adjacent end of R13 (labelled on the PCB overlay).
2. Connect wire to junction of C10 and C11 and bring it out the rear. This will be your +45V connection.



Alternative mounting for a TO-220 regulator instead of a TO-3. *EPE* PCBs will have a hole for the OUT pin, rather than the method shown here.

4V output for A+ filament supply

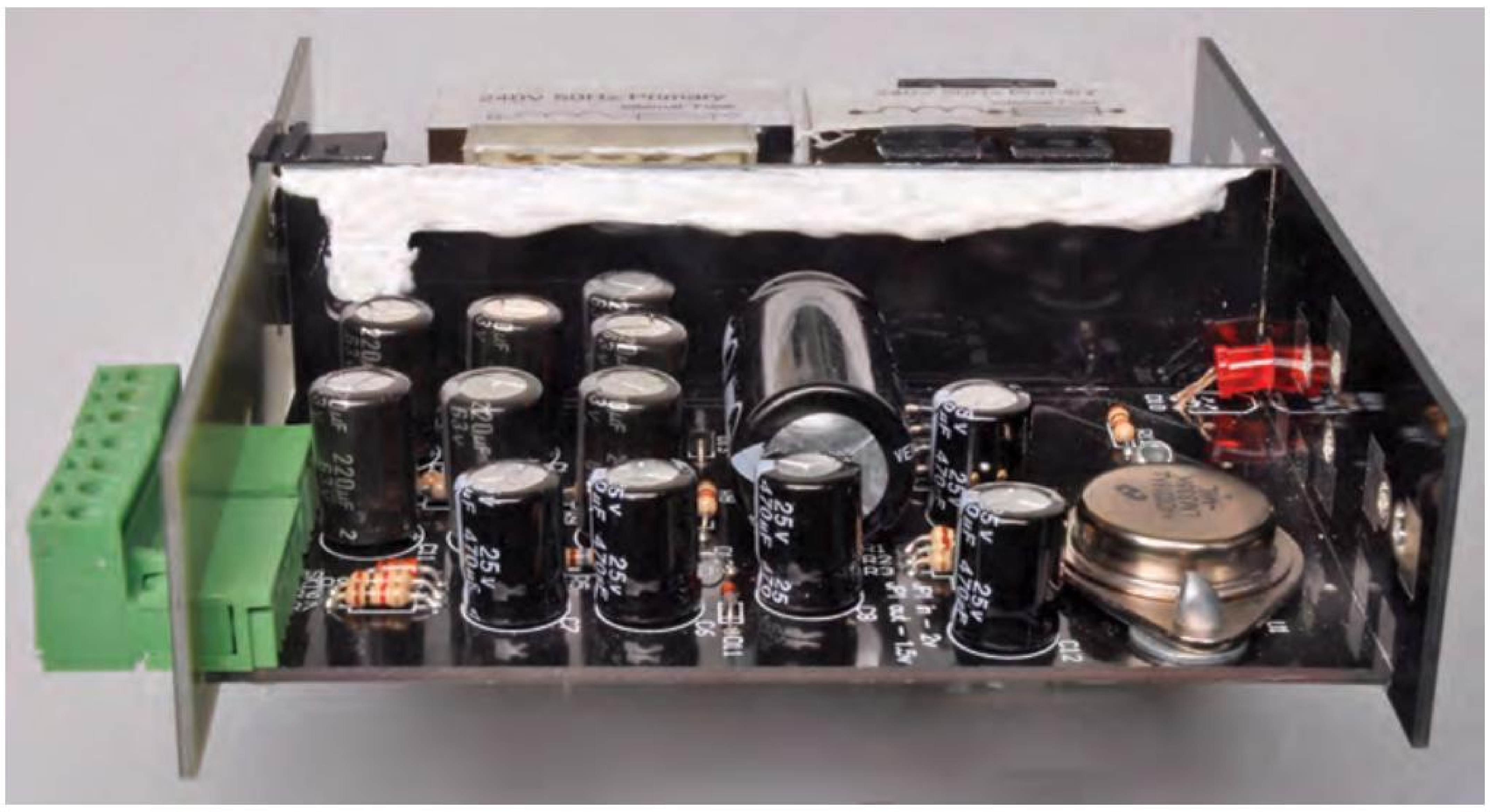
1. Replace R1 with 330Ω.
2. Fit jumper to JP1.
3. Replace the LM338K regulator with an LM1085IT-ADJ. Install it on a small heatsink as per picture earlier in these instructions.

This regulator has a lower dropout voltage than the LM317 or LM338. This should allow up to about 700mA current draw before hum appears on the output.

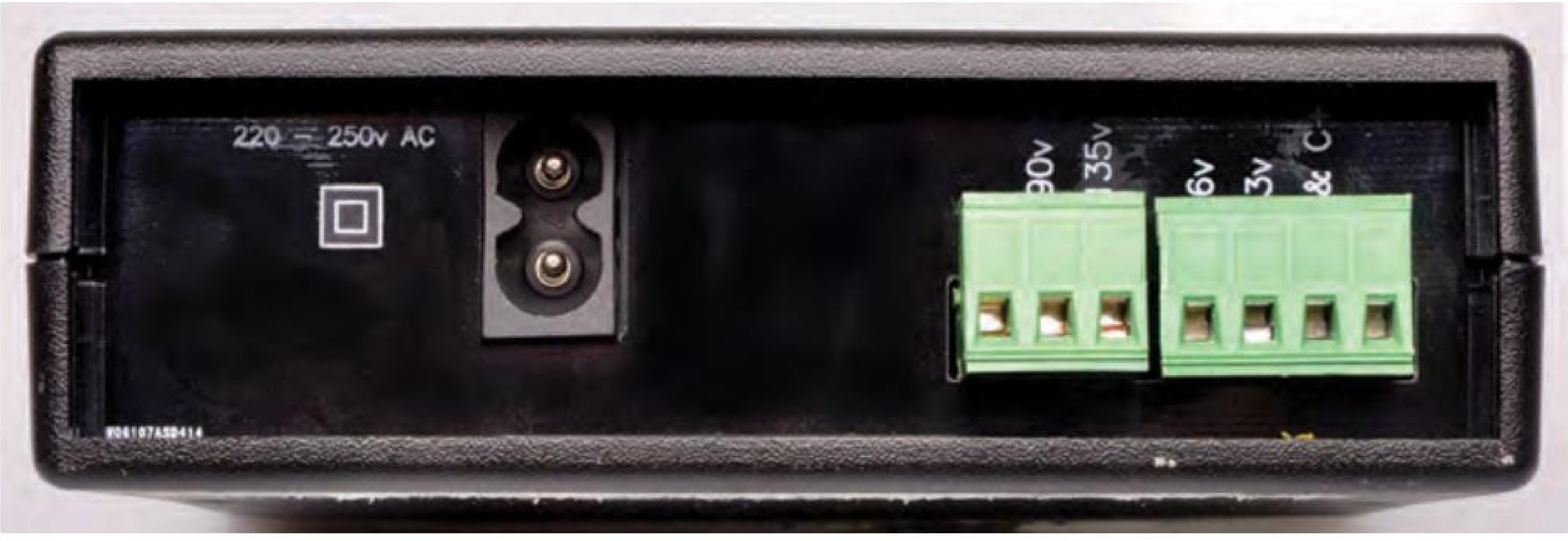
Different bias voltages

If you remove ZD1, the bias voltages will become (approximately) -7V and -3.5V. Changing R6 and R7 (or replacing them with a pot of about 2.2kΩ) will allow you to vary the bias to whatever your radio needs.

Note though, that the bias voltage is now not regulated and will change a little if the load on the filament circuit changes. Consider this if your radio has filament rheostats.



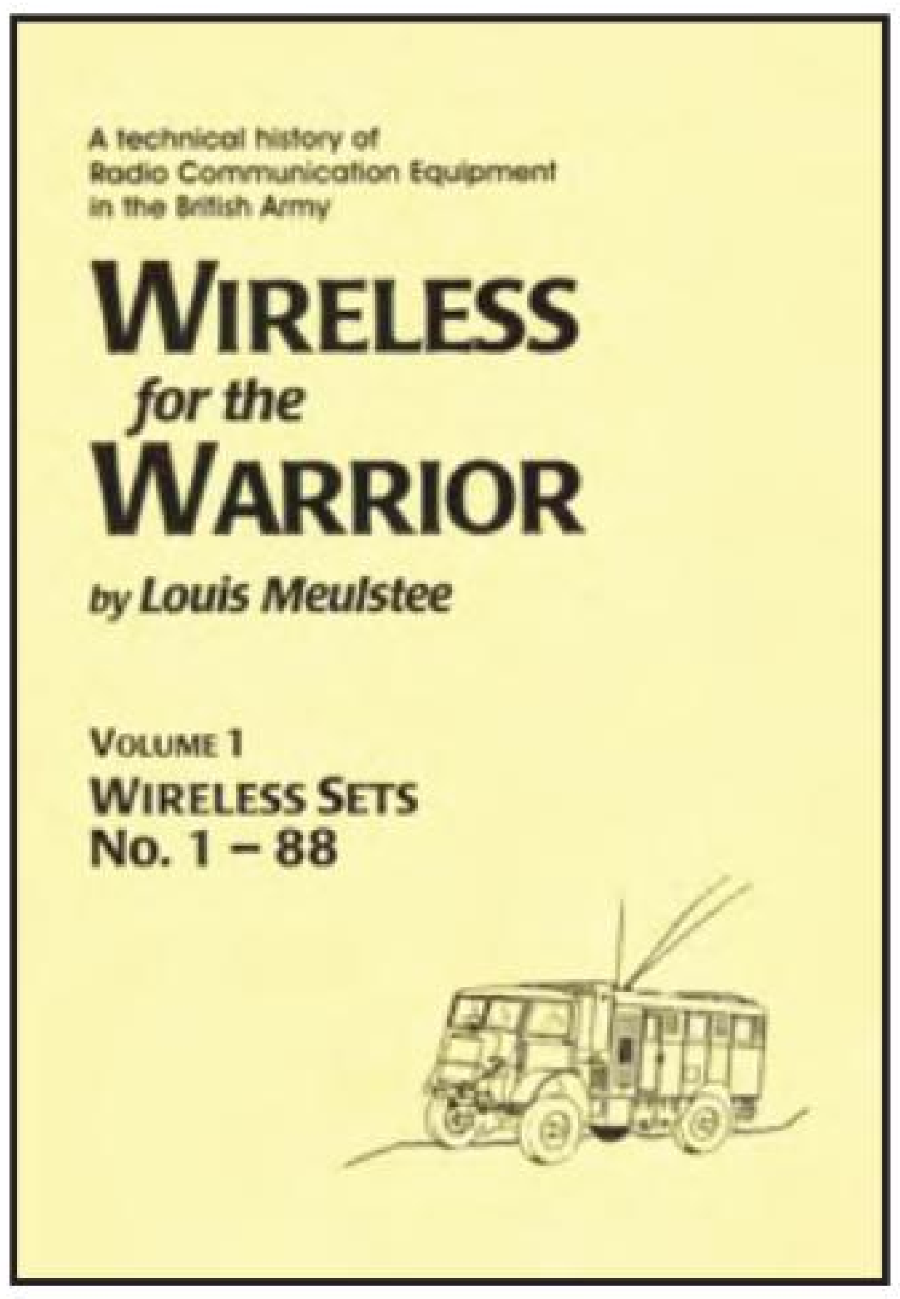
On the top side, the main board and front panel sit flush together so they can slip into the guides in the case. Here you can clearly see the silicone sealant we applied to the exposed mains terminals after testing. Mains voltages can bite you!



You can choose whether to have the front panel flush with the case and the rear panel inset (as shown here) or the opposite.

Wireless for the Warrior

A technical history of Radio Communication Equipment in the British Army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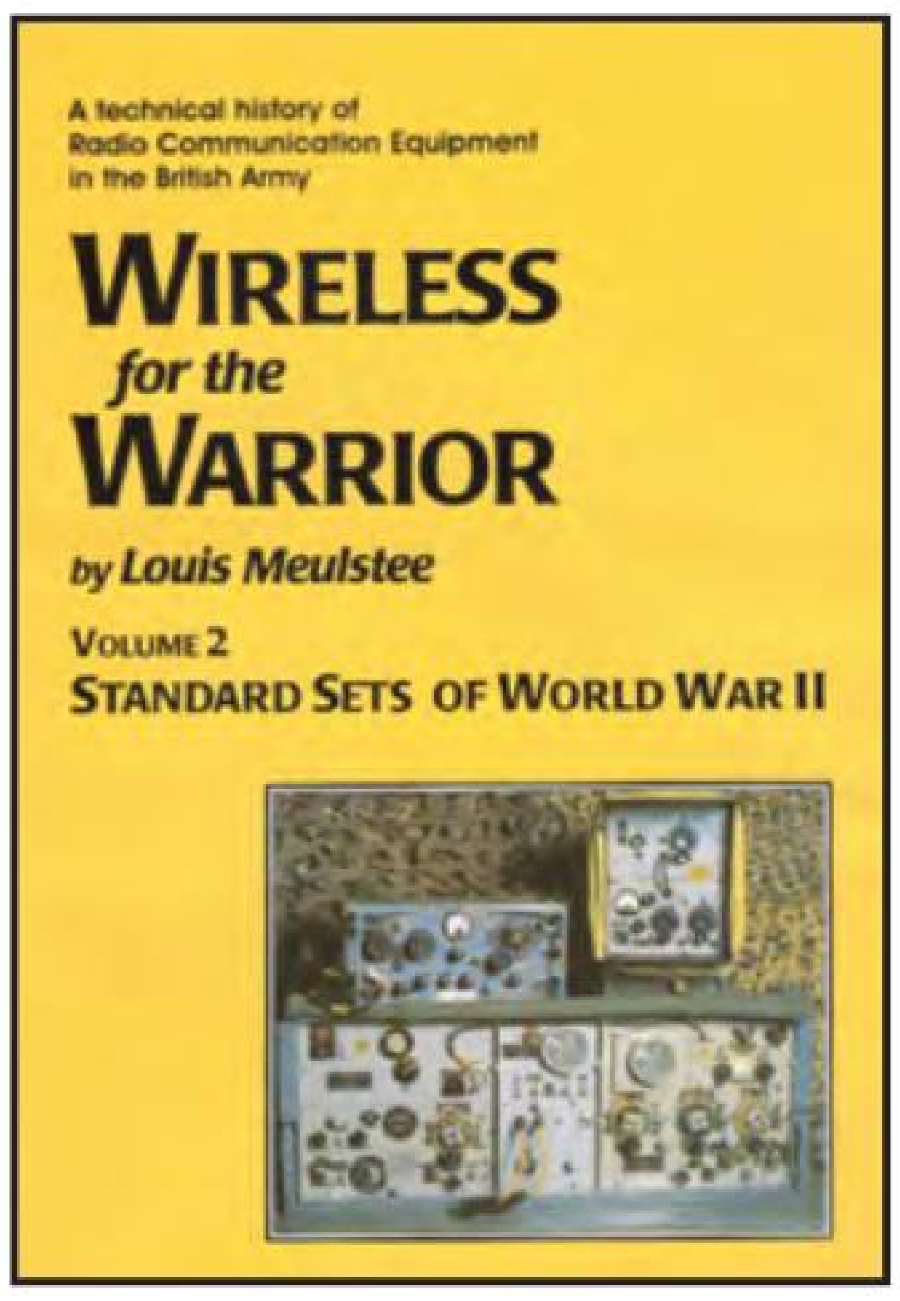
WIRELESS SETS No. 1 – 88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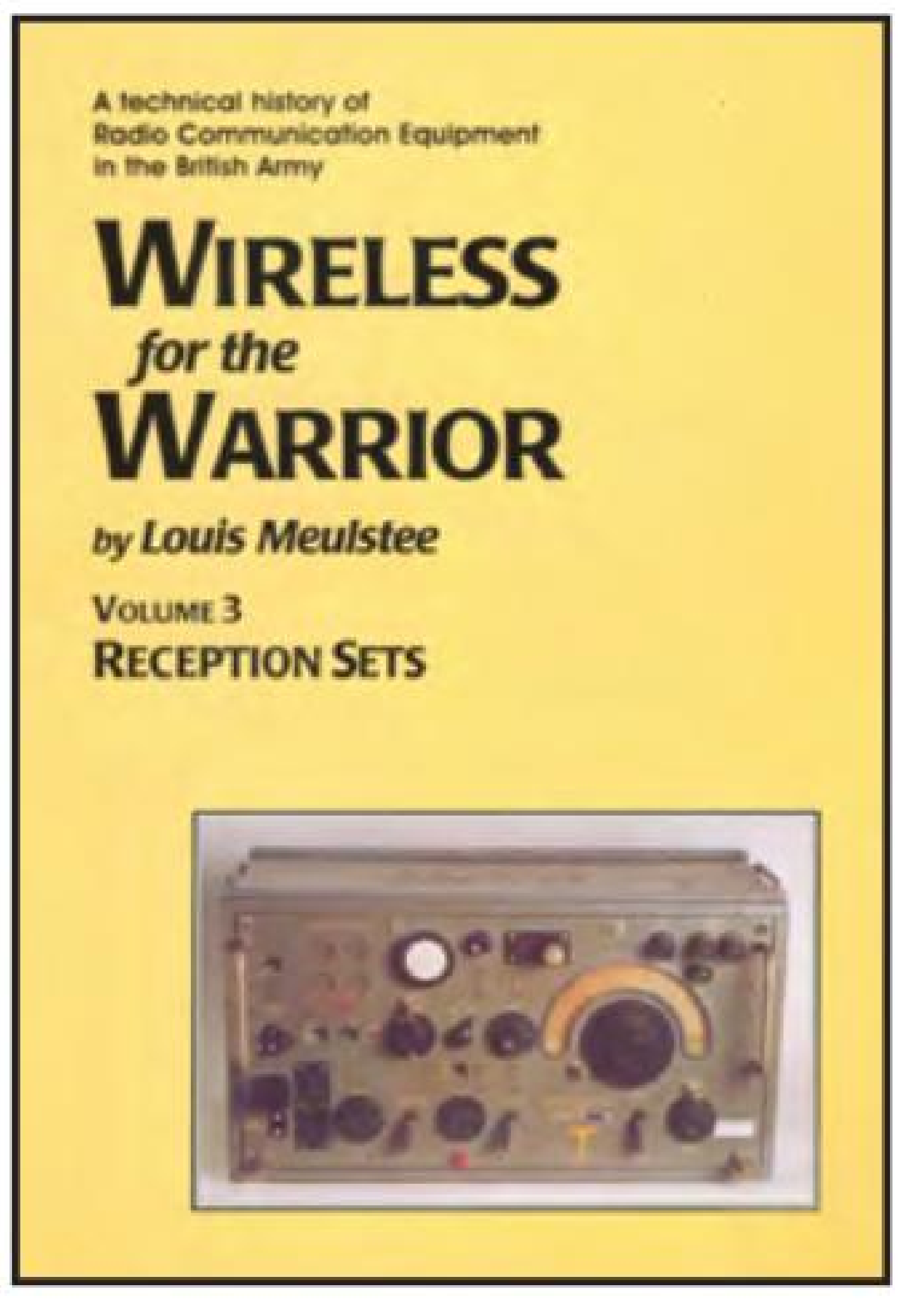
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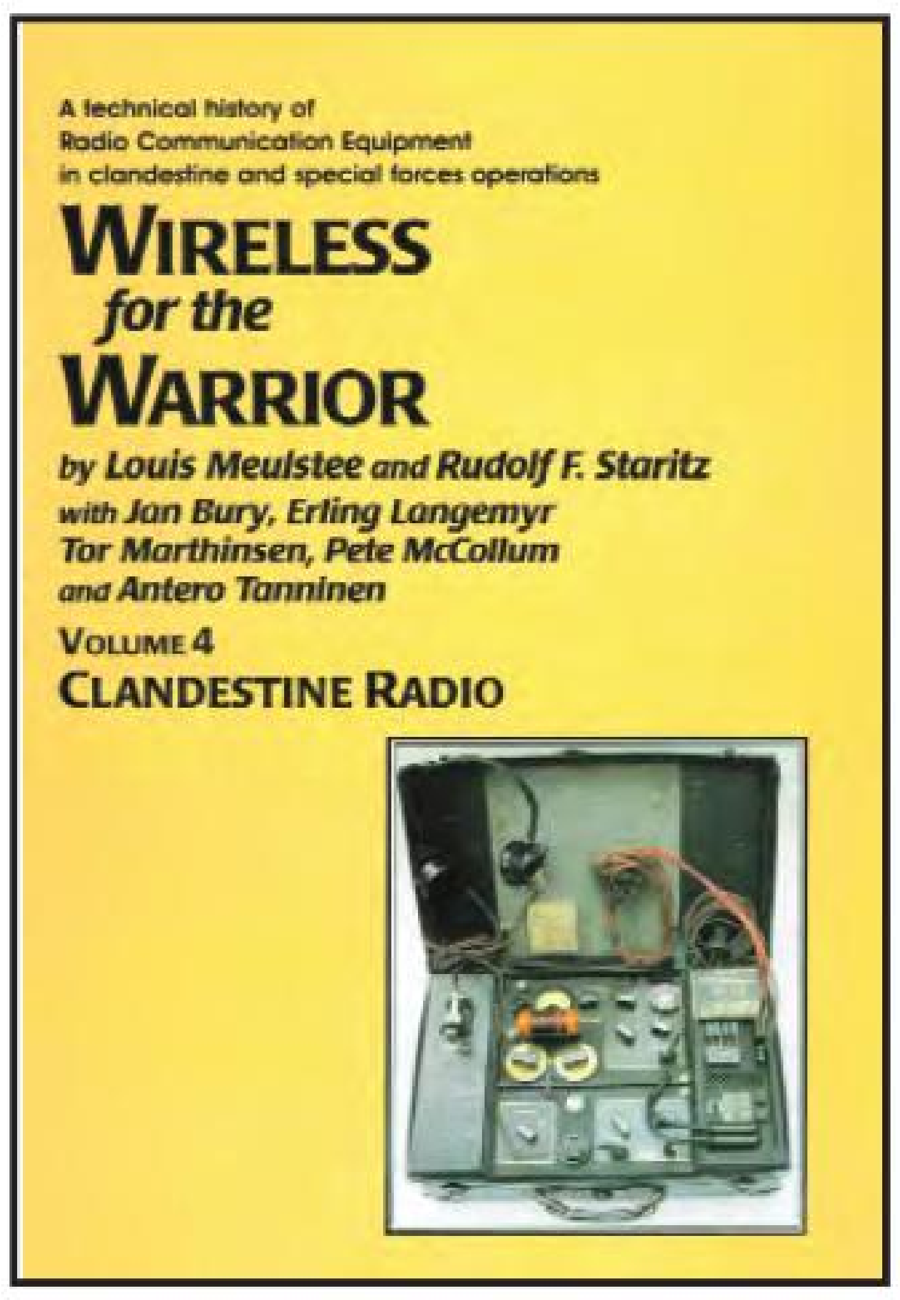
A technical history of Radio Communication Equipment in clandestine and special forces operations
WIRELESS for the WARRIOR
by Louis Meulstee and Rudolf F. Staritz
with Jan Bury, Erling Langemyr Tor Marthinsen, Pete McCollum and Antero Tanninen
VOLUME 4
CLANDESTINE RADIO

Volume 1 'Wireless Sets No.1 to 88' – covers the early radios, prior to the outbreak of World War II, and wartime sets which were never released in large quantities or were abandoned after trials. Volume 1 contains 360 A4 pages in softback format.

Volume 2 'Standard Sets for World War II' – provides information in detail of mass-produced Wireless Sets such as No.18, 19, 22 and 38. Additionally included are a number of post-war sets on which development had been started during World War II. Volume 2 contains 722 A4 pages in hardback format, and features more than 200 photographs, 750 line drawings and 180 data tables.

Volume 3 'Reception Sets' – the receivers described span the era 1932 to the 1960s, and coverage includes not only reception sets specifically designed or adapted for the British Army, but also sets adopted from other arms (RN and RAF), special receivers, direction finding receivers, army broadcast reception sets, Canadian and Australian army sets, commercial receivers adopted by the army, and army welfare reception sets. Volume 3 includes information on more than 70 receivers. It contains 546 A4 pages in hardback format, and features more than 230 photographs, 470 line drawings and 200 data tables.

***NOTES – 1.** Because of their weight and value, we recommend the use of airmail to dispatch Wireless for the Warrior, Volumes 2 and 4 outside Europe. **2.** These books exceed the printed paper postal weight limit of 2kg for Canada. Orders for that country will therefore be sent by surface post – this can take up to eight weeks.

Volume 4 'Clandestine Radio' A technical history of radio communication equipment in clandestine and special forces operations. Not only 'spy' equipment but sets used by Special Forces, Partisans, Resistance, 'Stay Behind' organisations, Diplomatic Service, Australian Coast Watchers, RDF and intercept receivers, bugs and radar beacons. The information has been compiled through the collaboration of a vast number of collectors and enthusiasts around the world. Volume 4 includes information on more than 230 sets and ancillaries. It contains 692 pages in hardback format, and features over 850 photographs, 360 line drawings and 440 data tables.

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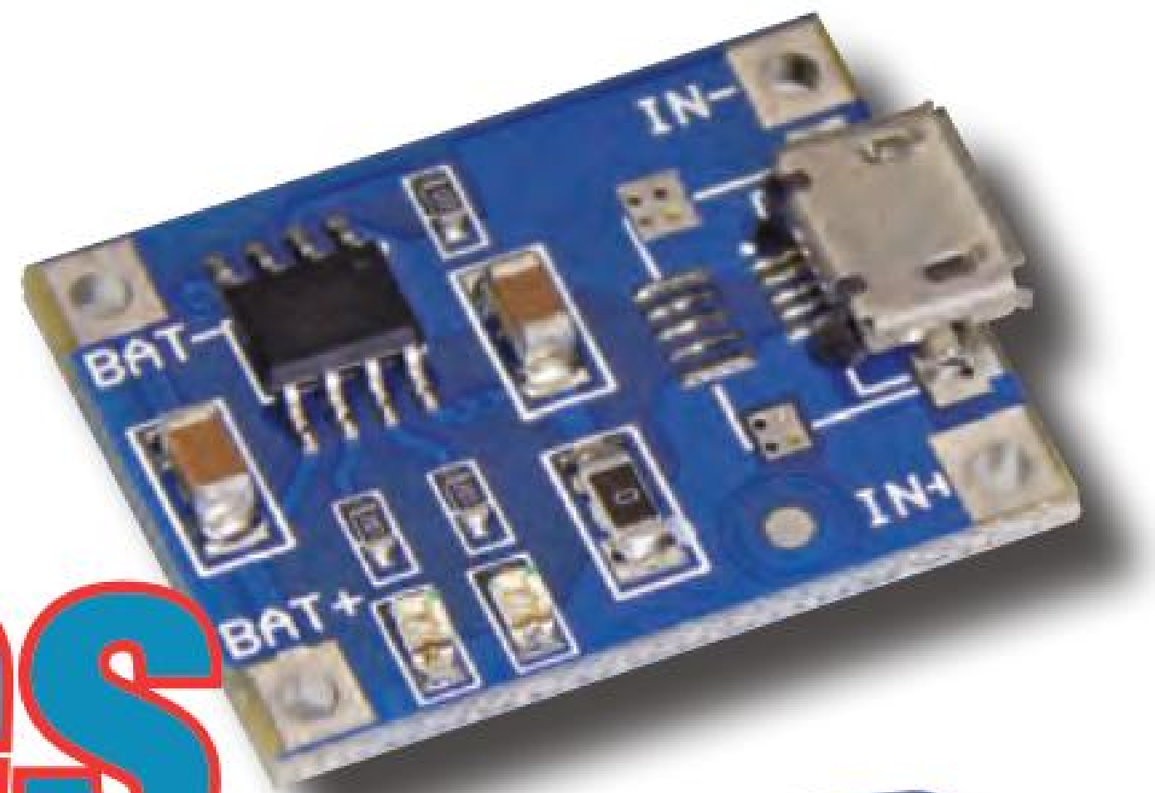
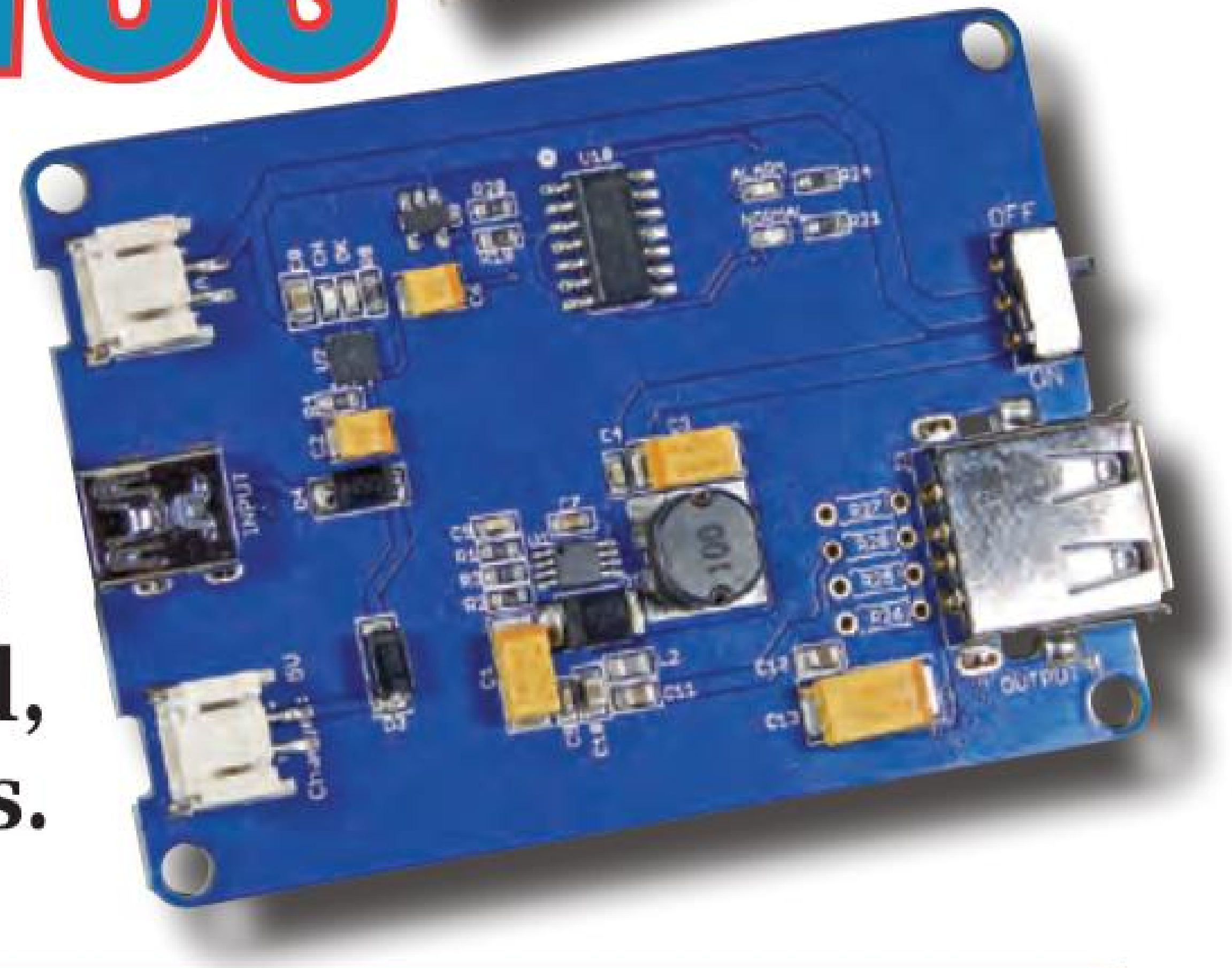
Li-ion and LiPo Charger Modules





These modules are designed to charge Lithium-ion and Lithium-ion polymer cells. One is low-cost and has a simple design, while the other sports an inbuilt DC-DC boost converter to provide a regulated output voltage from the Li-ion/LiPo cell, since its voltage varies as it charges and discharges.

Using Cheap Asian Electronic Modules Part 8: by Jim Rowe

Lithium-ion (Li-ion) and lithium-ion polymer (LiPo) cells and batteries are rapidly overtaking all earlier kinds of rechargeable energy storage. They're now being used in just about all mobile and cordless phones, in USB Power Bank devices used to recharge them, in laptop and tablet PCs and in many portable power tools.

Not only that, but it now looks like Li-ion/LiPo batteries are the preferred power source in the most successful current generation of electric cars, as well as providing some small-scale grid storage.

So it's not surprising that Li-ion/LiPo charging modules have now become readily available on popular internet venues like eBay and AliExpress, and we will be looking at three examples in this article.

Basic charger modules

Probably the most common charger modules you'll find on the web are those based on the TP4056 charge controller chip, like the one shown opposite in the photo at lower right. These modules are quite tiny, measuring only 26 × 20mm and they're currently available for just a few pounds each, even in small quantities.

There are a few minor variations, but most are very similar to the one pictured; and they are all slight variations of the circuit shown in Fig.1. Some are fitted with a micro-USB type B socket on the input side, while others have the slightly larger and more rugged mini-USB type B socket. You might choose this type since micro-B sockets can be a bit fragile and can even part from the module PCB when you're removing the USB cable.

Having said that, micro-B cables are very common and cheap because they are used to charge most modern smartphones, so that's a fairly strong reason to prefer the micro version, even if it's a bit more fragile.

As shown in Fig.1, there's little in one of these modules apart from the TP4056 controller chip itself. Made by Chinese firm Nanjing Top Power ASIC Corp, the TP4056 comes in a compact SOIC-8 package and provides all of the functions of a single-cell Li-ion/LiPo battery charger, powered from a 5V USB-compatible supply.

It follows the standard CC-CV charging protocol, with a maximum current of 1000mA (1A) in CC (constant current) mode and a maximum voltage of 4.2V (±1.5%) in CV (constant voltage) mode. Charging is automatically terminated when the charge current falls to 10% of the programmed value.

The charging current in CC mode can be programmed by changing the value of the R_{PROG} resistor connected between pin 2 of the IC and ground. As supplied, the module has a 1.2kΩ resistor fitted, corresponding to a charging current of 1000mA. If you want a lower charging current, you can select a higher value resistor – as shown by the table at upper right in the diagram.

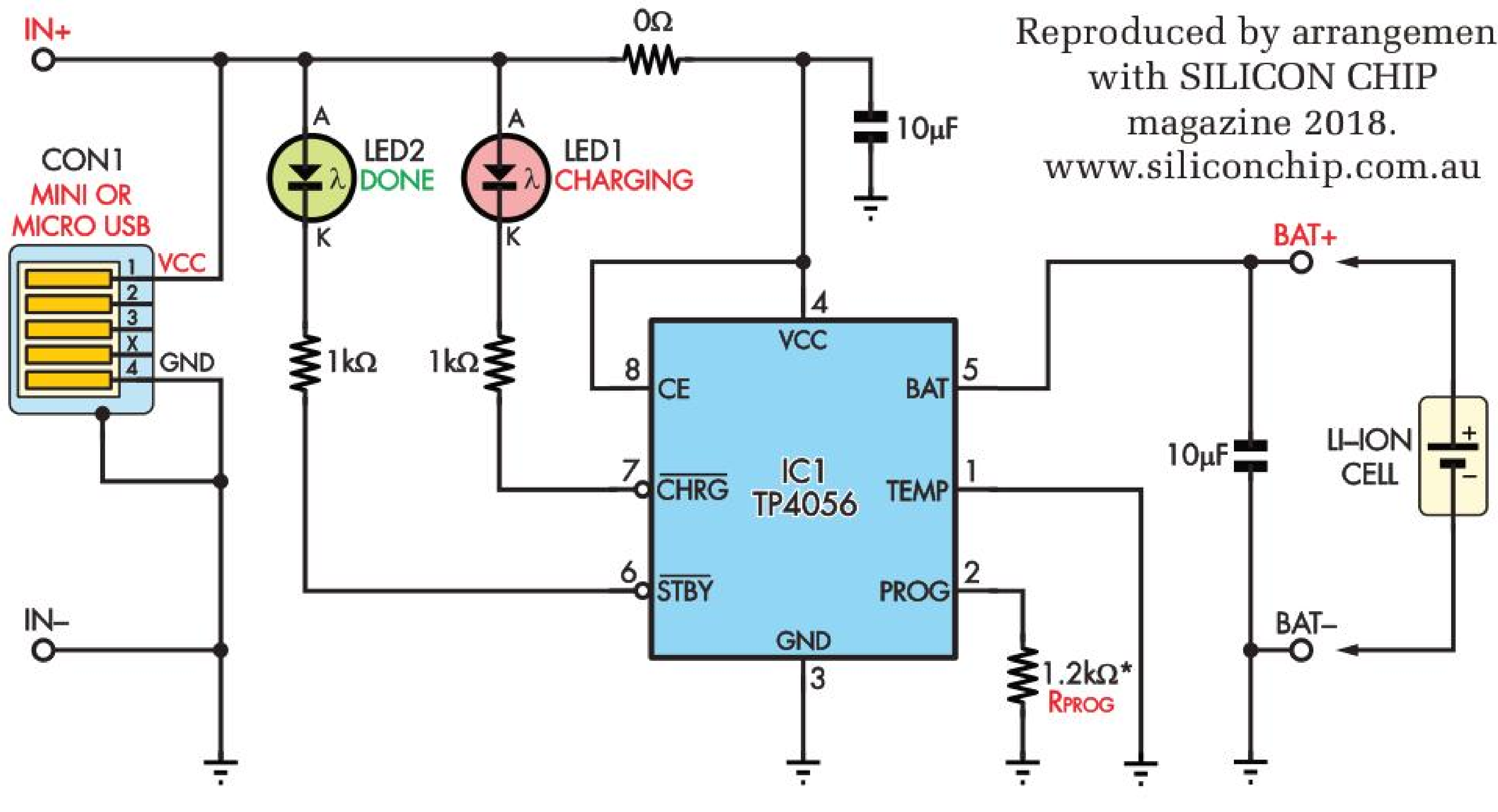
For example, if you replace the resistor with one of 2.0kΩ, the charging current in CC mode will drop to around 580mA. However, that should only be necessary if the cell you're charging has a capacity of less than 1Ah, which would make it quite small, and even some cells under 1Ah would be OK being charged at 1A; if in doubt, check the manufacturer's ratings for that cell.

As well as performing all of the charge control functions, the TP4056 also controls two indicator LEDs to signal the charger's current state. Red LED1 glows brightly during both charging modes (CC and CV) and ceases glowing when charging is terminated. Green LED2 only lights when charging is terminated. Both LEDs remain off if the USB input voltage is too low (<4.0V) or there is no cell or battery connected.

Note that if you want to power the charger from the USB port of your PC or laptop, it would be a good idea to change the value of R_{PROG} to 2.4kΩ so that the charging current is reduced to around 500mA; this is the maximum that should be drawn from the USB port of a PC (even though many ports will allow you to draw 1A if you try, at least for a short period). But if you are powering the charger from one of the 5V/1A USB plug packs, R_{PROG} can be left at its default value of 1.2kΩ.

That's about it for the basic versions of the USB-powered Li-ion/LiPo charger. They're cheap as chips but they actually do quite a good job of charging single cells and parallel-cell batteries.

Do keep in mind though that the TP4056 is a linear device, utilising an internal P-channel MOSFET to reduce the incoming supply voltage of say 5.5V down to the charging voltage of the cell, which could be as low as 3V when fully discharged. At a 1A charge current, that's a dissipation of (5.5V – 3V) × 1A = 2.5W which is quite substantial for an SOIC-8 package and it's likely to get quite hot under this condition (even more so if you run the chip at its maximum input supply rating of 8V).



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*DEFAULT VALUE. SEE TABLE AT RIGHT TO REDUCE CHARGING CURRENT

CHANGING THE CELL CHARGING CURRENT BY ALTERING THE VALUE OF RPROG

RPROG value:	1.2kΩ	1.3kΩ	1.5kΩ	1.8kΩ	2.4kΩ	3.3kΩ	4.7kΩ	8.2kΩ	12kΩ
IBAT in mA:	1000	923	800	667	500	363	255	146	100

Fig.1: circuit diagram for the basic TP4056 module. Note that many modules of this type will differ slightly from this circuit diagram.

This won't cook the chip since it has thermal regulation, which essentially means that it reduces the charging current if it gets too hot. But it does mean that it will take longer to charge the cell if you run into thermal limiting and the charging process won't be terribly efficient. Considering the size and cost of these modules, that really isn't a problem.

Fancier versions

In addition to the basic charger modules, there are more elaborate versions available. One of the most popular of these is shown on the next page. It's made by the firm Elecrow, based in Shenzen, China, and is about four times the size of the basic modules, measuring 68 × 49mm.

The circuit is shown in Fig.2. The actual Li-ion charger section is based around IC2 at the top. This is a Consonance CN3065 chip, which functions in much the same way as the TP4056 device used in the basic modules. As before, the CC mode current level is set via the resistor R_{PROG} connected between pin 2 (I_{SET}) and ground, and the default value of 2.0kΩ for this resistor gives a charging current of 900mA.

The CN3065 again follows the standard CC-CV protocol, with mode switching at 4.2V±1% and charging terminated when the current in CV mode drops to 10% of the programmed CC level. An interesting extra feature is that the cell voltage level at which the device switches from CC mode to CV mode can be raised above 4.2V by adding an external resistor between pin 5 (BAT) and pin 8 (FB). This will result in it reaching full charge sooner.

As with the TP4056, the CN3065 provides outputs to drive two LEDs. LED1 lights during charging, while LED2 lights when charging has terminated. Incidentally, the CN3065 is in a very tiny (3 × 3mm) DFN-8 leadless SMD package.

Another nice feature of the Elecrow PSB01012B charger is that it provides a choice of two DC inputs. One is via CON2, the mini-USB input socket, while the other is via CON1, a JST 2.0mm socket designated as the input from a solar photovoltaic panel. (A second JST 2.0 socket [CON3] is used for the Li-ion cell connection.) Schottky diodes D1 and D2 are used to feed the two inputs to IC2, so no input switching is required.

Note that the D– and D+ USB data lines of CON2 are taken through to USB output socket CON4, a standard USB type A socket. That's because the PSB01012B is not just a charger, but in effect a USB Li-ion power pack as well. It's also the reason for on-off switch S1, in series with battery connector CON3. But note that S1 will need to be in the ON position for charging to take place.

The other half of the Elecrow PSB01012B module provides a regulated +5V supply from the varying output of the Li-ion cell. This is the function of the circuitry around IC1, REG1 and IC3, in the lower half of Fig.2.

IC1 is the actual output voltage regulator. This is an Intersil ISL97516 device, described as a high-frequency, high-efficiency step-up (boost) voltage regulator, which operates in a constant frequency PWM mode. It's in a very small MSOP-8 package.

The ISL97516 operates at a nominal frequency of 620kHz or 1250kHz, selected by connecting pin 7 (F_{SEL}) to ground or pin 6 (V_{DD}). As you can see from Fig.2, in the Elecrow module it's programmed for 620kHz. The switching FET inside the device has a maximum current limit of 2.0A and an on-resistance of 200mΩ. As a result, it's claimed to deliver over 90% conversion efficiency – quite impressive.

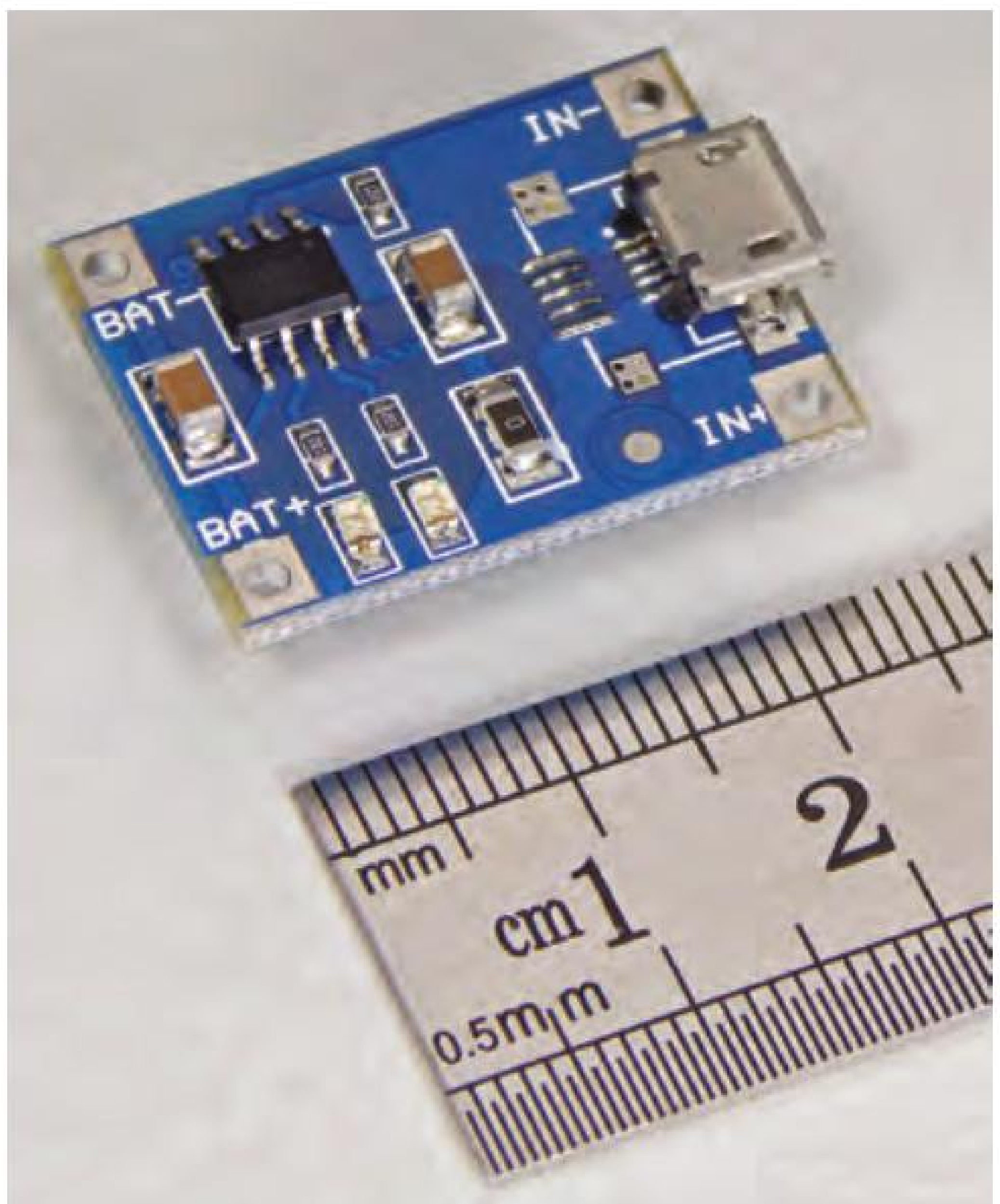
The input voltage range of the ISL97516 is rated at 2.3-5.5V, which is well suited to its application here. The output voltage range is specified as 5-25V. The actual output voltage is determined by the proportion of the output voltage fed back to pin 2 (FB) of the device, via a resistive divider. In the Elecrow module, the divider formed from the 43kΩ and 15kΩ resistors programs it to give an output of 5V.

Other attractive features of the ISL97516 include sensing of the current in the switching FET for thermal overload protection and a soft-start feature which allows slowing down of the internal oscillator's startup by connecting a capacitor from pin 8 (SS) and ground. As you can see in the Elecrow module, a 27nF capacitor is used for this.

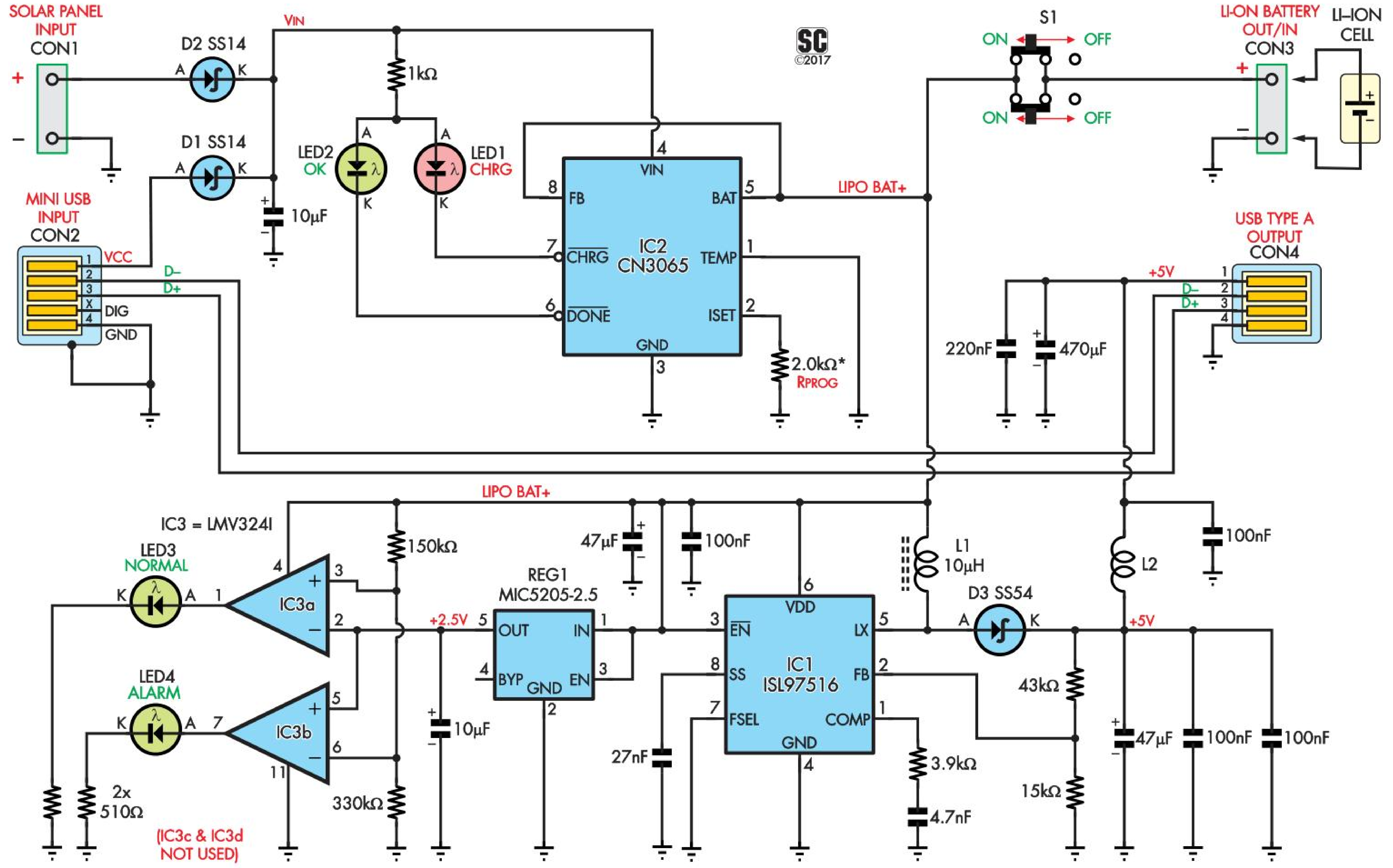
The regulated 5V output from IC1 appears across the 47µF capacitor at the cathode of diode D3 and is then filtered before being fed to pin 1 of the USB output connector CON4.

So that's the boost converter/regulator section. But what about the rest of the module's circuit, involving REG1 and two op amps in IC3? This additional circuitry is basically to monitor the Li-ion/LiPo cell voltage, and signal if it drops below a safe level. REG1 is a Micrel MIC5205-2.5 low noise LDO regulator, used to derive a 2.5V±1% reference from the cell voltage.

This is fed to op amps IC3a and IC3b, which are used as comparators. The second input of each 'comparator' is fed with a proportion (0.6875) of the cell voltage, derived by the resistive divider formed by the 150kΩ and 330kΩ resistors.



This TP4056 module shown uses a micro-USB[2] connector, but there are some that use mini-USB[1].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CON1
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D1 SS14
VIN
1kΩ
LED2 OK
LED1 CHRG
10µF
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VCC
D–
D+
DIG
GND
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CON4
+5V
220nF
470µF
IC3 = LMV324I
LED3 NORMAL
LED4 ALARM
IC3a
IC3b
150kΩ
330kΩ
2x 510Ω
(IC3c & IC3d NOT USED)
47µF
100nF
REG1 MIC5205-2.5
+2.5V
OUT
IN
BYP
GND
EN
10µF
IC1 ISL97516
VDD
EN
LX
SS
FB
FSEL
COMP
GND
27nF
3.9kΩ
4.7nF
L1 10µH
L2
D3 SS54
43kΩ
15kΩ
47µF
100nF
100nF

*DEFAULT VALUE, GIVING A CURRENT OF 900mA IN CONSTANT-CURRENT CHARGING MODE.
(ICH (amps) = 1800V/ RPROG in ohms)
SEE TABLE AT RIGHT FOR VALUES OF RPROG FOR DIFFERENT CHARGING CURRENT LEVELS.

CHANGING THE CELL CHARGING CURRENT BY ALTERING THE VALUE OF Rprog

RPROG value:	1.8kΩ	2.0kΩ	2.2kΩ	2.7kΩ	3.6kΩ	4.7kΩ	6.8kΩ	8.2kΩ	10kΩ
IBAT in mA:	1000	900	818	667	500	383	265	220	180

Fig.2: circuit diagram for the Elecrow PSB01012B charger module which utilises a CN3065 IC instead of the TP4056 detailed earlier (the CN3065 is functionally identical to the TP4056).

This voltage is fed to the positive input of the IC3a comparator and the negative input of the IC3b comparator. As a result, whenever the divided-down cell voltage is above +2.5V, IC3a turns on LED3 to indicate that the cell voltage is OK.

By contrast, if the divided-down cell voltage falls below +2.5V, IC3a turns off LED3 and IC3b turns on LED4 to indicate that the cell is nearing the limit of safe discharging. This occurs at 2.5V ÷ 0.6875 = 3.64V, a little above the minimum recommended discharge voltage to achieve the best cell lifespan.

So the Elecrow charger module with its inbuilt +5V output regulator provides significantly more capabilities than the basic modules. It actually provides all of the functions needed for making your own USB Power Bank, using a Li-ion or LiPo cell/battery of your own choosing. Plus, it has the ability to charge your Li-ion/LiPo cell from a solar panel.

So although it will cost you significantly more than one of the basic modules, it's still good value for money.

Trying them out

I tried a couple of the basic TP4056-based charger modules with both a single 18650 Li-ion cell and a battery of two parallel-connected 18650 cells. The chargers did everything that could be expected from them, charging the cells repeatedly with no problems – apart from the micro-B USB input socket breaking away from one of the modules when I tried to unplug the cable from the USB plug pack. Hence my suggestion to prefer the mini-USB socket version.

I also tried out one of the fancier Elecrow PSB01012B modules, although this did involve getting hold of some cables with the very small JST 2.0 connectors (for the Li-ion cell cables, to connect to CON3).

As a charger, this one worked just as well as the basic modules. But where it really shone was on the output side, being able to provide a regulated +5V output (or reasonably close to it; about 4.85V) for the USB device connected to CON4's output, even for a load drawing 500mA and with a partly discharged Li-ion cell with a terminal voltage down to about 3.8V.

In fact, it kept providing this regulated output voltage even when the Li-ion cell dropped down below 3.0V, after about 40 minutes. Quite impressive! (But not recommended if you want your cell to last a long time.)

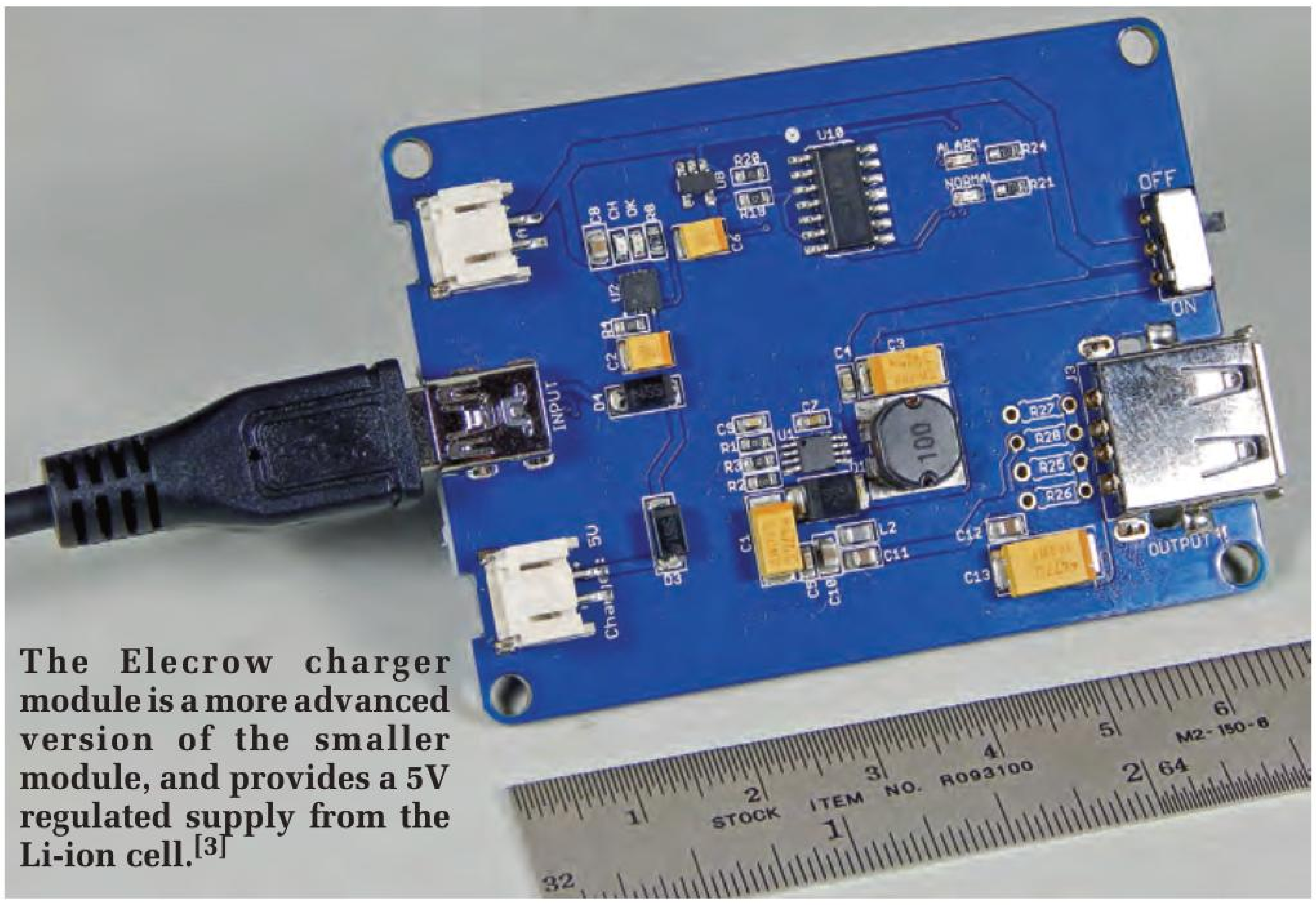
It might seem to be nit-picking, but I'd like to have seen the Elecrow module's regulated USB output closer to the nominal +5V under load than 4.85V. If you calculate the expected output voltage for IC1, you get 1.294V × (43kΩ ÷ 15kΩ + 1) = 5.0V, so this is likely a component tolerance issue that requires trimming.

This could be achieved by measuring the actual output voltage and then paralleling the 15kΩ resistor with a higher value SMD resistor, by soldering it on top. For example, in my case, the output needs to be raised by (5.0V – 4.85V) ÷ 4.85V = 3.1%, so a resistor of 15kΩ ÷ 0.031 = 483,870Ω or say 470kΩ should do the trick.

I also think that ALARM LED4 should ideally be a red one, not another green one as it is at present. It's right next to green LED3, making it difficult to see when LED4 has lit up. You could fix this by de-soldering LED4 and fitting a red LED in its place.

My only other complaint about the Elecrow module was that the very small slider switch used for power switch S1 was very flimsy. Perhaps it had been damaged in transit, but at one point the tiny actuator almost came out of the switch body – not a good sign.

One more point – it would be a good idea if the unit could be set up to automatically switch off the output if the cell voltage drops too low, to prevent damage from over-discharge. Some



The Elecrow charger module is a more advanced version of the smaller module, and provides a 5V regulated supply from the Li-ion cell.[3]

Li-ion and LiPo cells have internal over-discharge protection circuitry, but many do not. It would be possible to modify the module to provide this function, by cutting the track to pin 3 of IC1 and soldering it to output pin 1 of IC3a instead.

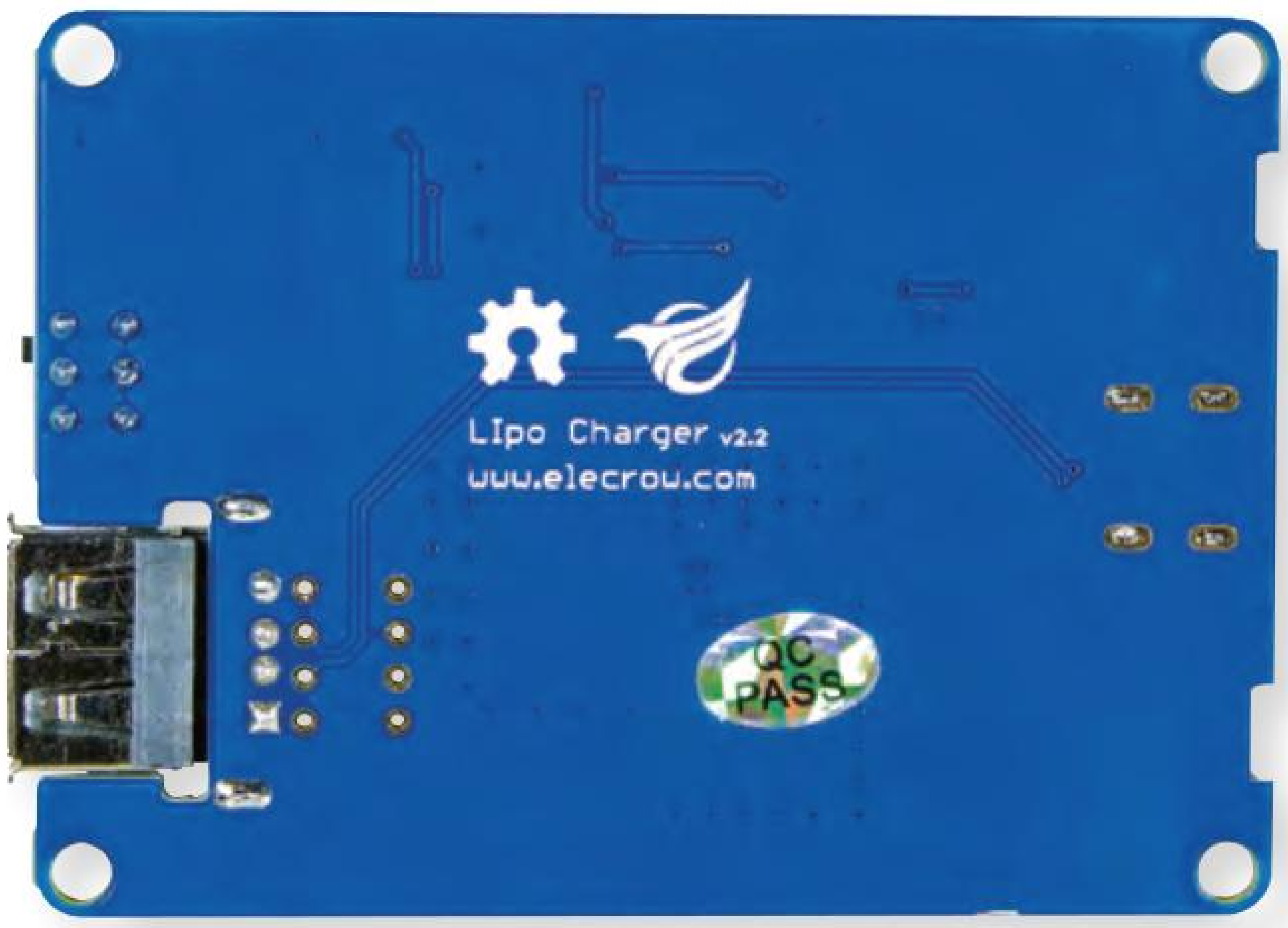
However, note that this would cut off the output at the aforementioned cell voltage of 3.64V, which is a little high; ideally, alarm LED4 should light before the cell is discharged to the point where the output switches off. A second threshold in the range of 3.0-3.3V would do the trick, but that would require a number of extra components.

Smaller Elecrow module

It was only after I had checked out the Elecrow PSB01012B module that I learned about their other 'mini' module. Luckily I was able to get a hold of one of these quickly, in order check it out as well.

As you'd expect from the circuit (Fig.3), its performance as a Li-ion cell charger is very close to that of its bigger brother – it just takes a little longer to charge, because of the lower default charging current level.

It functions in a very similar manner but is significantly smaller (46 × 32mm), costs less and they have made some tweaks to the design. It uses the same CN3065 chip for charging as the larger module. However, unlike the larger module, it does not have a power switch, so the load is always powered.



There isn't much going on underneath the Elecrow module, except for a few tracks and the eight through-hole pads provided for D+ and D– biasing resistors.[3]

I was interested in measuring the performance of its DC-DC boost converter, because of its greater simplicity. And I was pleasantly surprised, because the converter in the mini module was just as good as the one in its big brother.

Even though its output voltage under 250mA of loading was slightly lower at 4.80V with a cell voltage of 3.84V, it only dropped to 4.78V when the cell voltage fell to the recommended minimum of 3.0V. So it might be a lot simpler, but it's just as impressive in terms of conversion efficiency.

The other differences are as follows. First, the input power socket is a micro type-B, rather than mini. Second, the output current capability is lower, at 500mA compared to 1A.

They have also added a JST 2.0 2-pin output connector in parallel with the USB output, and added a pass-through function, which feeds the input voltage directly through to the output when it is present, to reduce the load on the cell.

There are a couple of drawbacks to this module, though. Note that the USB and solar inputs are wired in parallel, so there's a possibility of current being fed back into the USB source, which would be bad. Also, if the USB supply voltage is high enough, Q1's body diode could allow current to pass into the cell, bypassing IC1 and possibly leading to over-charging.

This is likely a design oversight and will probably be fixed in future revisions, but could be solved by placing a diode in series with Q1; a notable omission from the design.

The bottom line

Overall then, all of these modules seem to work quite well. The basic charger modules are fine if you just want to charge a Li-ion/LiPo cell (or two in parallel), although I would recommend the version with a mini-B USB input socket rather than a micro-B socket, for the greater robustness.

With the enhanced Elecrow PSB01012B and mini variant, the main reason to go for the larger PSB01012B module is for its 'through path' for the USB signal lines between the input and output, and for its use of the more reliable mini-B USB input connector.

One final note: if you want to use either a basic charger module or one of the fancier modules to charge one of the flat pack LiPo cells, then you'll probably need to get a matching charging cradle to make reliable connections to the contacts on the end of the cell. These cradles are available at quite a low price from sites like eBay or AliExpress, although some of them come with their own inbuilt chargers.

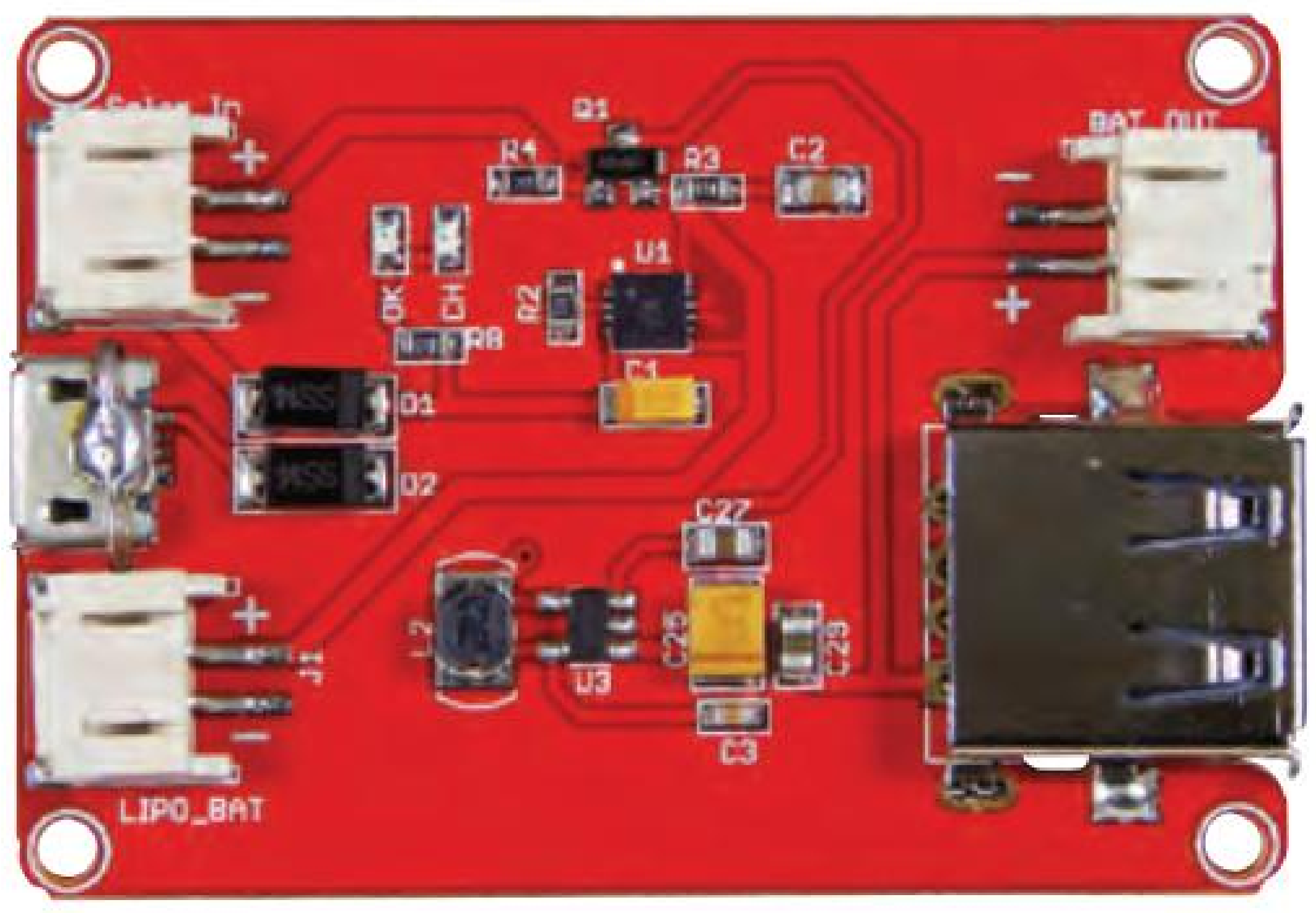
Finding the charging modules

All of these chargers are available on the Internet; here are some tips:

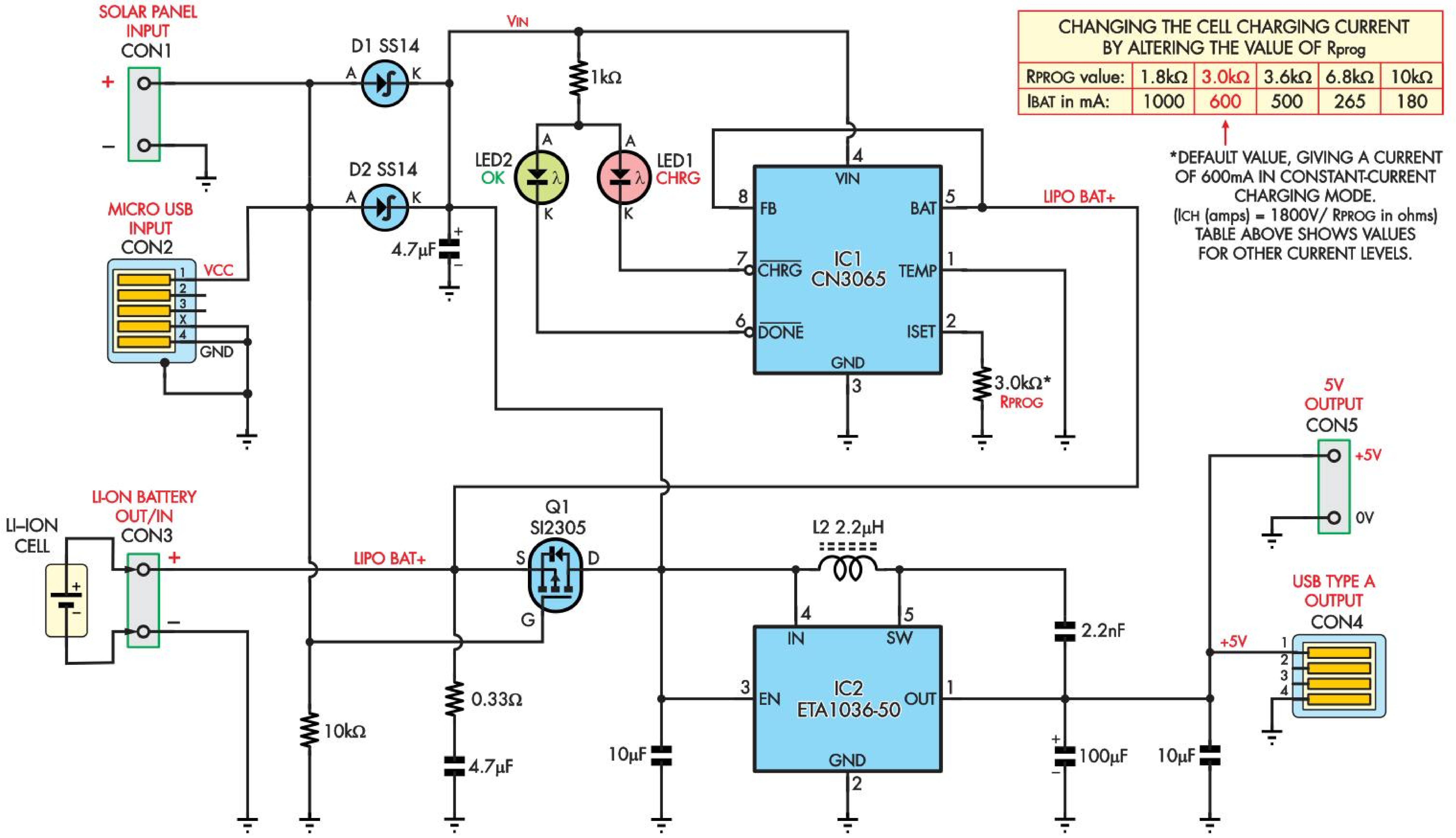
1) TP4056 1A Li-ion/LiPo charger with mini-USB socket is available from **eBay.co.uk** – for example, item 222179387315.

2) TP4056 1A Li-ion/LiPo charger with micro-USB socket is available from **eBay.co.uk** – for example, item 332563978016.

3) Elecrow CN3065-based 1A Li-ion/LiPo charger with 1A step-up circuit, USB pass-through and power switch;



The mini Elecrow module is a decent bit smaller (46 × 32mm) than the larger variant (68 × 49mm).[4]



CHANGING THE CELL CHARGING CURRENT BY ALTERING THE VALUE OF Rprog

RPROG value:	1.8kΩ	3.0kΩ	3.6kΩ	6.8kΩ	10kΩ
IBAT in mA:	1000	600	500	265	180

*DEFAULT VALUE, GIVING A CURRENT OF 600mA IN CONSTANT-CURRENT CHARGING MODE.
(ICH (amps) = 1800V/ RPROG in ohms)
TABLE ABOVE SHOWS VALUES FOR OTHER CURRENT LEVELS.

Fig.3: circuit diagram for the smaller Elecrow charger module. The DC-DC boost converter is much simpler than the larger Elecrow module and is based around an ETA1036-50 synchronous converter chip (IC2; SOT23-5). This allows for a drastic simplification of the boost converter to a 2.2µH inductor, four SMD capacitors plus the IC. Q1 allows the incoming 5V from USB or a solar cell to power IC2 directly, bypassing the cell.

68 × 49mm, mini type-B USB input, full-size type-A USB output, two JST cables included is available from **elecrow.com** – item PSB01012B.

4) Elecrow CN3065-based 1A Li-ion/LiPo charger with 500mA step-up circuit; 46 × 32mm, micro type-B USB input, full-size type-A USB output, three JST cables included is available from **elecrow.com** – item CPC09141S.

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Racal 9300B	As 9300	£75
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Lucy's Lab

Dr Lucy Rogers explores the frontiers of electronics for hobbyists and makers

Soldering – when did you learn?

I had a go at soldering at school, but to be honest I can't remember much about it other than some burnt fingers and a coughing fit. At university, I think I only ever used breadboards – I don't remember soldering anything – even though I did electronic as well as mechanical engineering in my first and second years.

During the next fifteen years or so, I would sometimes find a need to solder something (usually a repair where a wire had become detached) – but cheap soldering irons were hateful to use and resulted in a lot of swearing. It was only about five years ago that I purchased my own controlled-output soldering iron. Shortly followed by a solder sucker.

I bought it because I wanted to start connecting things to my Raspberry Pi – and I discovered that connecting a 3V motor to the 3.3V GPIO pins was a bad idea. The GPIO pins only works with logic-level signals. This means each pin supplies 3.3V but only a few mA of current – enough to power an LED. But to control anything more powerful, like a motor, requires additional circuitry to boost the current and/or voltage to a higher level. My first soldering attempt was to make an open-collector driver to do this. I recently found that board, and it still works – but the soldering is awful! Splatters, lumps, and burns all over the stripboard. Fortunately, my soldering (and electronics) skills have improved a lot over the last few years.

I am not sure where the transition occurred between soldering being a chore – having to make a large mental effort before I would solder something – to picking up the soldering iron and using it without really thinking. Nor when I learnt how not to breathe in the solder fumes without just holding my breath. I hadn't even realised I had made that transition until a school friend recently came round and made the Tindie kit badge I was given at the UK Makerfaire. It required about 15 soldered joints, but she hadn't touched a soldering iron since school. The kit is good as an intro, with some blinking lights to show it all works. However, the instructions suggest you start with soldering the fiddly switch and only later apply a big blob of solder to hold the non-electrically connected pin clasp. It would have been easier the other way round. I was impressed at how quickly my friend went from 'what do I do?' (and swearing) to 'this is fun' to 'yay! finished!'. I am not sure she is now a converted electronics hobbyist, but she won't be put off from soldering something in the future – should the need arise. And I did give her the most important piece of advice – 'never try to catch a falling soldering iron'. However, I think that advice only works *after* you have tried to catch one at least once.

USB soldering iron

The start up cost of soldering has reduced dramatically. The cheap irons of even five years ago have been replaced with ones that actually work quite well. I recently acquired a £5 USB soldering iron. I must admit I was still dubious about how well it would work, even though Les Pounder has done a lovely review: **http://bigl.es/tuesday-tool-ing-usb-soldering-iron/** and Big Clive did a very positive YouTube teardown: **https://youtu.be/o-8D5t6TJYU**.

So far, I have only used it for tinning wires and soldering them to an LED, but it seems very capable for those jobs. As Clive mentions, if used with a USB wall socket, there is a small risk of passing AC voltage to sensitive components – however Les has never found a problem with it and he now uses his USB iron for the majority of his soldering work.

Yours for a fiver – search for 'USB Soldering Iron Pen Portable' on eBay.

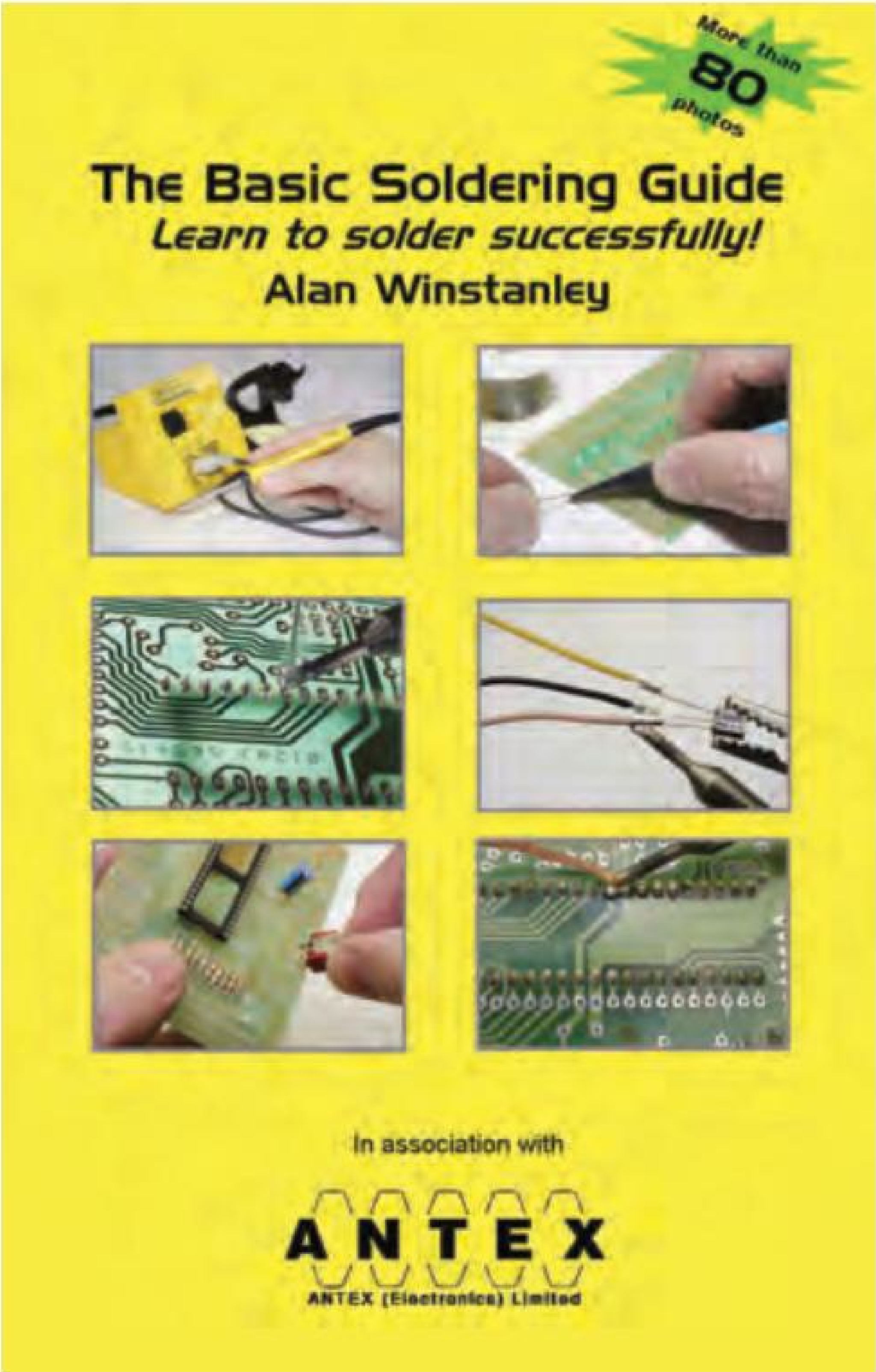
One for the hackapack

I have used it plugged into a USB battery pack. I am not sure how long this would be good for yet, but I made about twenty joints with it. Along with a 'helping hand' lump of Blu-tak, this is a truly 'in the field' soldering kit. Therefore, I have added it to my trusty 'hackapack' – a grab toolbag for short trips, which don't justify taking a full-size toolbag, but when I want something 'just in case'.

Richard Sewell first introduced me to the concept of a hackapack – and he has blogged and photographed his kit here with pictures: **www.jarkman.co.uk/catalog/robots/robottoolkit.htm**. Gone are the days when all I took was a Swiss Army knife. But then, gone are the days when all I really needed to do was sharpen a pencil or wire a plug. And I still haven't ever got anything out of a horse's hoof!

Leaning to solder?

No discussion of learning to solder is complete without mentioning fellow *EPE* columnist Alan Winstanley's, *The Basic Soldering Guide*. This excelent introduction is available from *EPE*: **http://bit.ly/2LjTWi3** or Amazon – strongly recommended!



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NET WORK

by Alan Winstanley

None of your business

Readers will no doubt have received a blizzard of GDPR emails heralding the new General Data Protection Regulation, sometimes from companies that they'd either never heard of, or simply forgotten altogether. The GDPR became EU law on 25 May 2018 and promises to clamp down on the misuse of personal information. However, it's proving to be a nightmare to implement for many online companies.

For EU citizens, the GDPR is good news; for starters, the days of presumptive, pre-ticked opt-in boxes are over as they don't constitute users consenting to their data being harvested and processed. How to opt out (from future communications, say) must also be clearly explained up front. After decades of seeing commerce playing fast and loose with personal details, we are promised strict control of how our data is processed, though serial spammers will probably ignore GDPR and continue to take liberties with it.

Last month, I mentioned how Facebook forced new Terms & Conditions onto its users (see screenshot, *Net Work*, July 2018), adopting a take-it-or-leave-it approach to implementing its upgraded data policy. On GDPR day, the Center for Digital Rights (**NOYB.eu**) (strapline: 'My Privacy is None of Your Business') filed complaints against Facebook, WhatsApp and Instagram (both owned by Facebook) as well as Google, over what it deemed was this 'forced consent' to personal data processing. It was pointed out that this was considered a flagrant breach of the GDPR and something that smaller firms would never get away with. NOYB was founded by Maximillian Schrems, a brilliant young Austrian lawyer who, as a result of legal action he was taking against Facebook in Ireland, ultimately helped bring down the Safe Harbor framework that saw EU citizens' data being routinely exported to the US. It was argued that US standards of data protection were inadequate and personal data was possibly being harvested by the NSA (citing information in the Edward Snowden leaks). Consequently, the supposedly more compliant Privacy Shield Framework hastily replaced Safe Harbor: **www.privacyshield.gov**

The principles of privacy and personal data protection have come under the microscope like never before. At the time of writing, having warmed to its task, Britain's Information Commissioner's Office (ICO) is doing what governments do best. It is publishing all manner of self-assessment toolkits, PDFs and video slides and pointing to swathes of EU law churned out by the EU's Article 29 Working Party, leaving hapless organisations to figure it out for themselves, even though the ICO's finalised guidance won't be available until December. Many small organisations are struggling with the GDPR and, to be on the safe side, they are requiring customers to opt in to all future communications all over again, hence the avalanche of GDPR emails that everybody is receiving.

Also heading through Parliament is the new Data Protection Act 2018 (DPA) which complements the GDPR and seeks to enshrine the new EU Law Enforcement Directive (LED) which prepares Britain to legally share data with EU police and intelligence agencies after Brexit.

The GDPR has been four years in the making, and no doubt it will take time for its implications to sink in, especially for a healthcare clinic located somewhere in England: as I write this piece, it mistook my Gmail address for that of their patient, and they emailed me my namesake's forthcoming appointment, as well as his postal address. I quickly rebuked them, but clangers like that, or emailing whole groups of recipients using To: instead of BCC: (Blind Carbon Copy) may become very costly mistakes to make in the future. The fall-out has only just started, and we will hear far more about the impact of GDPR for many years to come.

- **GDPR is of course a 'Regulation' not 'Requirement; apologies for my error last month.**

Adoring Eudora

Given a choice, I am not the greatest fan of cloud computing, and for reasons of trust, speed and control I prefer to run dedicated software locally to handle mail, graphics, accounts and design on a home-brew PC system. Regular readers may recall my item last year (*Net Work*, March 2017) about Eudora, a legacy email program that still has many followers, despite some minor niggles (display fonts and HTML email, for starters). If nothing else, Eudora is sprightly and I can run powerful searches of a decade's worth of mail within seconds. It runs well in Windows XP, 7 and 10, and is great for those who like to compose or manage email offline, rather than logging in somewhere, or for techie PC users who like to back up their own mail locally as needed. As regards security, it's true that hackers could try eavesdropping on a session running between Eudora and a mailserver (unlikely but you never know), just as mobile users who don't use a virtual private network could unwittingly connect to an insecure hotspot operated by criminals and get hacked – highly unlikely, but still possible.

It was Qualcomm that engineered and sold Eudora for many years before free email clients like Outlook Express made paid-for email programs redundant, and gradually everyday non-corporate users migrated to user-friendly, cloud-based Hotmail or advertising-snooping Gmail instead.

For the writer – and many other Eudora users – comes the welcome news that the Computer History Museum (CHM) in California recently acquired the Eudora program source code after five years of talks with Qualcomm. The CHM published the fascinating history of Eudora at **https://tinyurl.com/ya9yyp8d** from where the source code can be fetched (the 122MB alpha release is aimed at developers.) It looks like work is already under way on refreshing this powerful email program, with source code for one proposed version called **Hermes Messenger** (the Eudora name can't be used) becoming available in the past few days, see: **https://sourceforge.net/projects/hermesmail**

It's unclear if Eudora's brilliant X1 Search engine can be included due to third-party licensing issues. (A Windows version of X1 Search costs $96 from **www.X1.com** and it parses desktop files as well as Outlook 2007+, Gmail and some other mail clients. A 14-day trial is available.) The days of handling email offline are far from over, and I'm sure many Eudora and Thunderbird fans look forward to enjoying a modernised PC version of this faithful email client sometime in the future, perhaps based on Hermes Messenger.

First light, now heat

With the EU's energy savings drive in mind, traditional fire-breathing incandescent bulbs for domestic use are fast becoming extinct, CFLs remain unloved and halogen bulbs are gradually being supplanted by modern LED technology. Some remarkable LED bulbs are now on sale, including LED filament lookalikes, and despite their higher up-front cost, LED bulbs offer instant-on illumination and some irresistible energy savings. A huge range of them is sold by CPC (**www.cpc.co.uk**) and others.

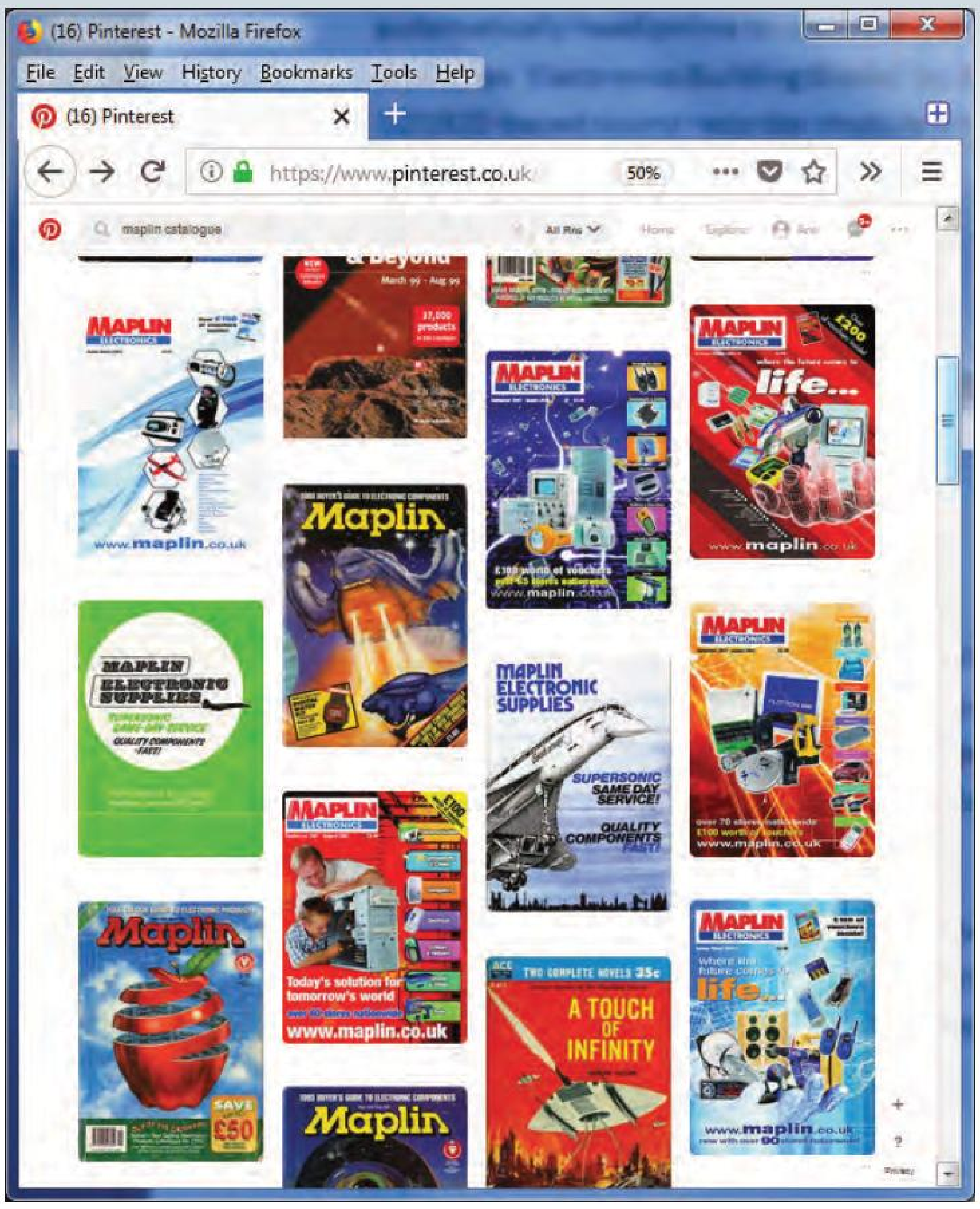
Future generations of LED lovers will look upon our old tungsten filament bulbs with horror and they will probably think the same of our heating systems too. In Britain, a soft-launched move has been under way since January to implement energy and emissions savings in the electric and space heater market. Under the EU Ecodesign Directive, new 'Lot 20' compliant heaters must incorporate energy-saving features such as thermostats and timers, open-window sensors to prevent heaters running continuously and, optionally, 'presence detectors' that power down when the room is empty.

Dimplex, the favourite old British brand of electric heaters has produced an excellent online guide at **www.lot20.co.uk** explaining how the EcoDesign Directive affects no less than 37 areas or 'lots'. Lot 20 relates to space heating. If you are looking to buy electric, gas or liquid fuel heating for autumn, then check for the benefits of Lot 20 compliance and maybe also be aware of some market disruption that might arise with stocks of old designs running out before new ones are ready.

Very Pinteresting

The shutters finally came down on the website of Maplin Electronics (**www.maplin.co.uk**) at the end of April 2018, and sadly its chain of retail stores will probably have closed for good by the time you read this. Nostalgia isn't what it used to be, as the quip goes, and after scouring Google Images for some old Maplin catalogue covers I logged into Pinterest, the social-media-type website devoted to curating images and sharing them with followers (registration required). Pinterest members can 'pin' web images to their own 'board' and they can also follow like-minded users, building up a library of images – whether for inspiration, interest or nostalgia – based on those pinned to other Pinterest boards. It's worth noting that a board of images is public and therefore visible to other users by default, so when creating your own board consider whether to make it 'secret' (for your eyes only), via settings in the control panel. Note also that Pinterest also displays the usernames of everyone who has saved an image to their own (public) board.

You could pin recipes, wallpaper designs, or microcontroller news articles into separate boards of your own, but you can also bookmark holiday destination websites, DIY projects or anything else that appeals to you. There are pin-out diagrams, resistor code graphics and tons more to appeal to the electronics hobbyist. A 'Read It' or 'Visit' button will click you through to the image's originating website, which can often give you a toehold in other websites or blogs that might appeal to you. Toolbar buttons offered by Pinterest for various web browsers are supposedly available, but I have yet to install them successfully. If the idea of browsing around image libraries or organising your own cloud-based collections appeals to you, why not give Pinterest a try by setting up an account at **www.pinterest.co.uk** (or your local country), or download the Pinterest app for Android or iPhone.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Pinterest is a searchable resource of images, in this example showcasing old Maplin catalogues

Last, this month, for those who may be interested, I delve into more of Maplin's history and reasons for its downfall at **www.alanwinstanley.com** where visitors are welcome to share memories or views. You can also email the writer at **alan@epemag.net**

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PIC n' Mix

Mike O'Keeffe

Our periodic column for PIC programming enlightenment

My return and the PICkit 4

AFTER a few months of spending quality time with my wife and new-born twin boys, surviving on minimal sleep and copious amounts of coffee, I'm back for more PICs and terrible puns. During my absence, Mike Hibbett did a fantastic job keeping *PIC n' Mix* ticking over with his series on dsPICs and the FFT (Fast Fourier Transform). If you haven't read his articles yet, I highly recommend them (April to July, *EPE*) and do build the project. Mike's articles were a real treat, and as always, he's a tough act to follow. Fortunately, I enjoy a good challenge and Microchip has provided the perfect excuse to re-enter the *PIC n' Mix* column with a bang – an important new product launch.

PICkit 4 launch

While I was away, Microchip launched their latest programmer and debugger, the PICkit 4. I can almost hear the collective sigh of despair from those anticipating impending digital heartache! For many of us, the transition from the PICkit 2 to the PICkit 3 was a difficult move. Indeed, some have stayed with their PICkit 2 over the PICkit 3 for reasons of reliability and functionality. The *initial* release of the PICkit 3 lost a host of features from its predecessor, including the serial decoder. However, it seems Microchip have taken note of their previous decisions (mistakes/fumbles/slow software releases) and are really trying to up their game with the ambitious feature set promised for the PICkit 4.

The introduction of a new product often brings concerns around shunting much-loved (and useful) predecessors into obsolescence, which in this case means worry about the continued support of the PICkit 3. Hopefully, Microchip will support the great functionality of PICkit 3 for years to come – or at least until the initial bugs of the PICkit 4, inevitable in any new product release, have been properly ironed out.

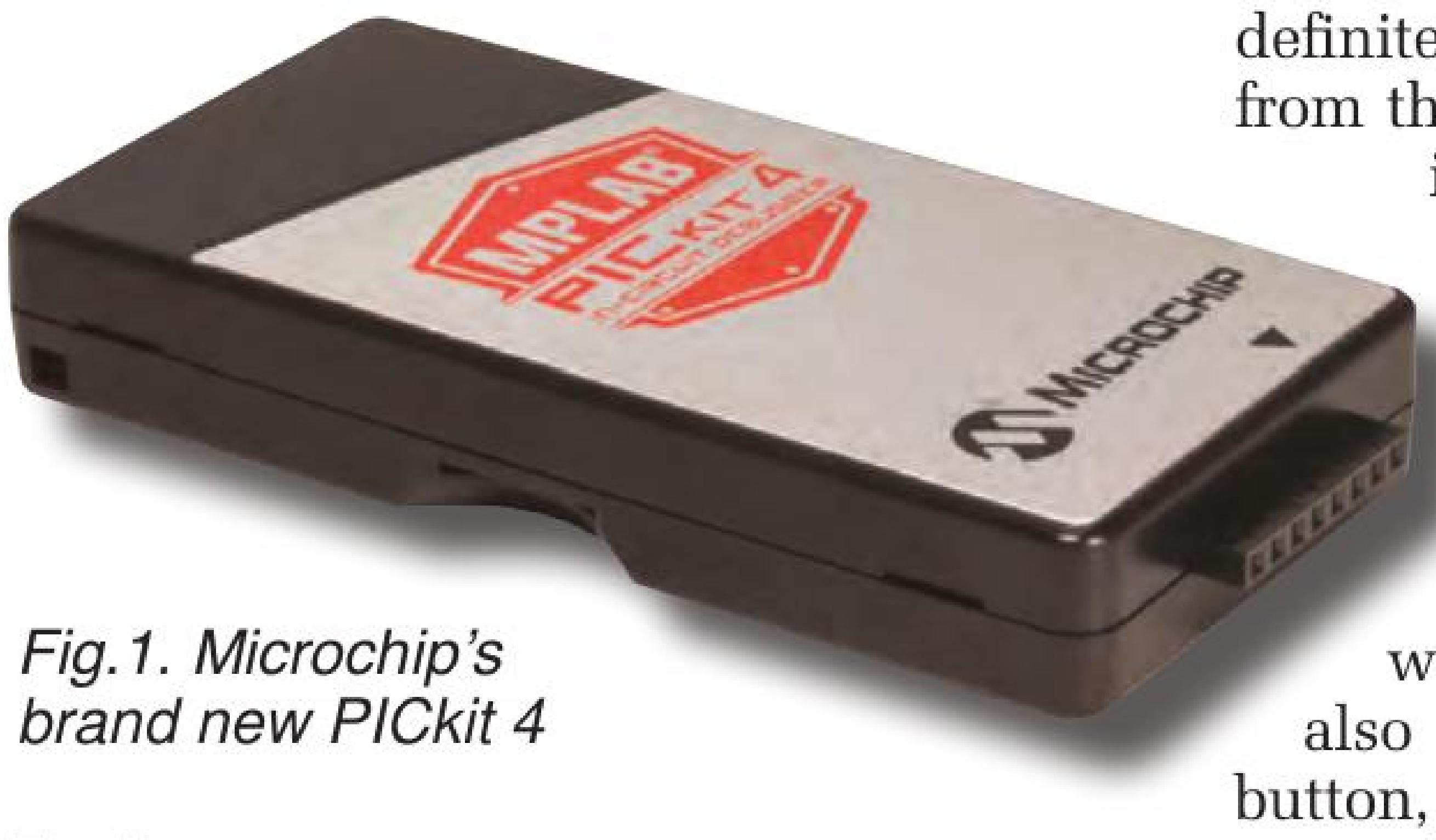


Fig.1. Microchip's brand new PICkit 4

Features

Coming in around the same price mark as the PICkit 3, the PICkit 4 boasts some interesting features that will make it a serious contender in the low-cost programmer and debugger market, certainly setting it apart from its predecessors. On top of the usual 2-Wire JTAG/ICSP interface with the Programmer To Go (PTG), it also adds the 4-wire JTAG and SWD interface for ARM Cortex microcontrollers. A microSD Card slot is added to store images for programming on the go. It can also be powered by the target, enabling easier programming in the field. A wider target voltage supply range from 1.2V to 5.5V with up to three decimal point accuracy adds greater custom voltage options.

Learning from previous mistakes in the PICkit 3, the PICkit 4 has brought back the UART interface, along with serial-wire debug with streaming data gateway and SPI interfaces.

Look and feel

The PICkit 2 and PICkit 3 were fairly similar in appearance. The former was black, the latter a translucent red. However, the designers of the PICkit 4 definitely want to make sure we know from the outset that their new product is more than a 'mere' upgrade. The casing is rectangular, matt black with a metallic front panel, adding an air of sophistication (see Fig.1). An updated red logo is a subtle reminder it is meant for use with the MPLAB X IDE. The logo also hides the Programmer To Go button, which programmers activate by squeezing the case.

Across the front of the case is a single diagonal light guide, which changes colour based on programming progress. Around the back is the microSD card slot. The device is powered by a micro-USB connector, replacing the previous bulkier, mini-USB version. A small pin hole with a hidden button can be seen at the top of the programmer, this is to enable recovery boot mode.

One key item to note is the addition of two extra pins on the programming header (see Fig.2). Maintaining legacy connections with older designs for the first six pins, the additional two add some extra features. (First small warning for upgraders here – the extra pins may be an issue for existing designs that have tight board access for just the previous six-pin header of the PICkit 3.)

Under the hood

Taking a look under the hood, in Fig.3 we see a custom-designed light guide for the diagonal indicator on the outside of the case. It is a little over the top, but it is nice looking.

The big silicon change is the upgrade from the 16-bit PIC24FJ256 in the PICkit 3 to the ATSAME70Q21, an

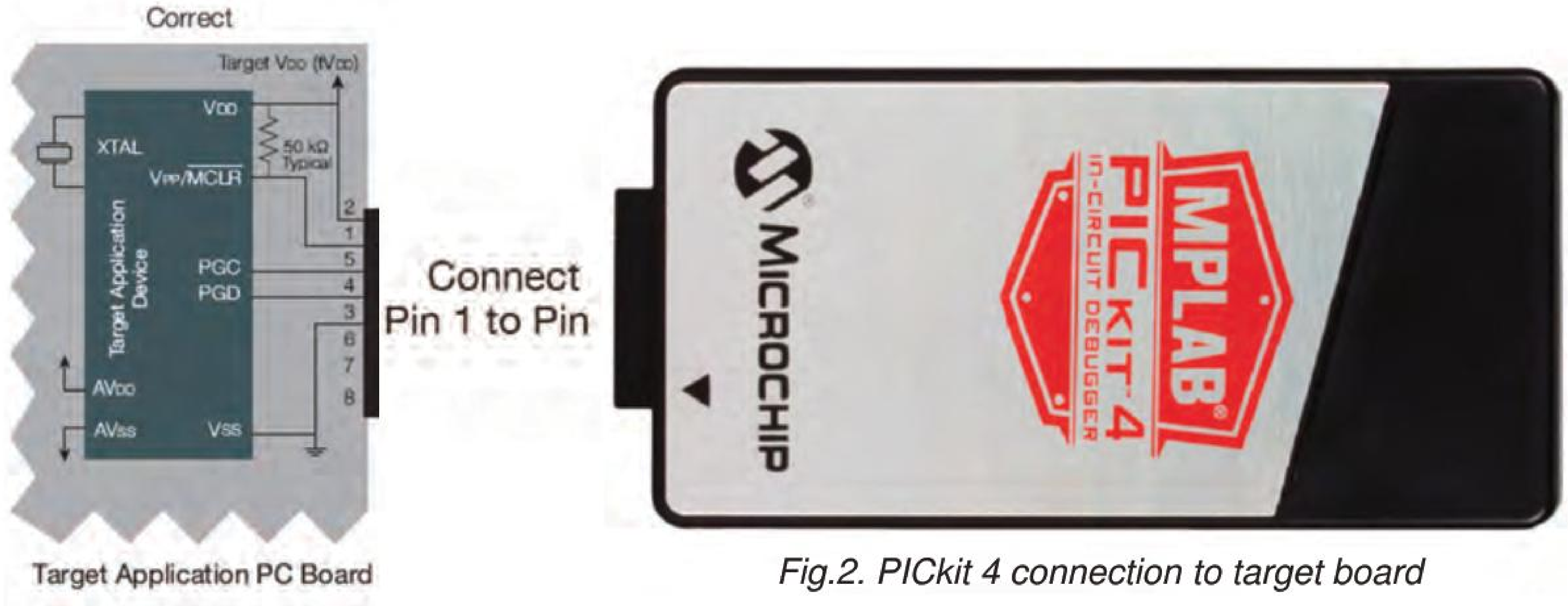


Fig.2. PICkit 4 connection to target board

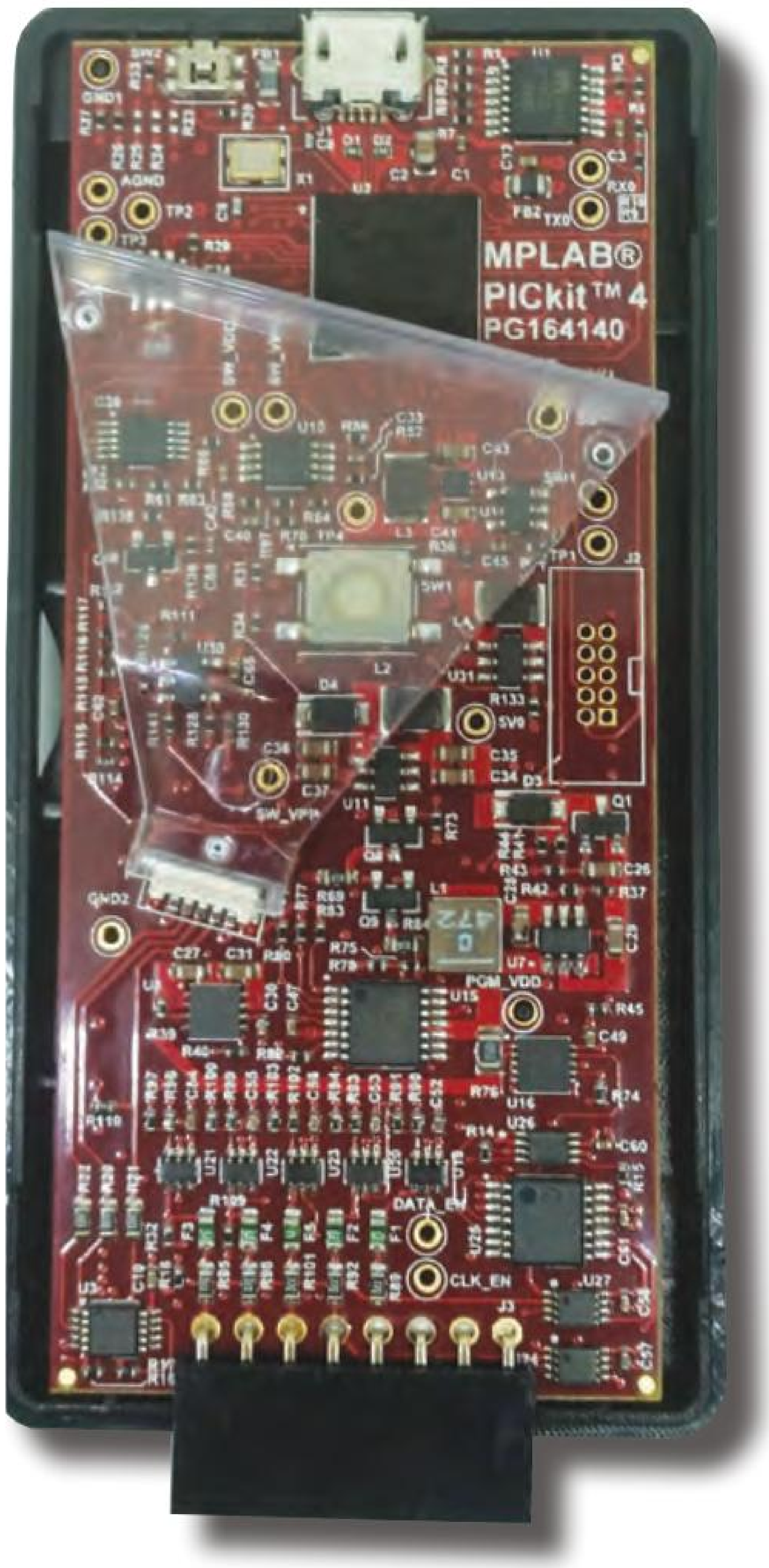


Fig.3. Under the hood of the PICkit 4 – note the transparent LED light guide

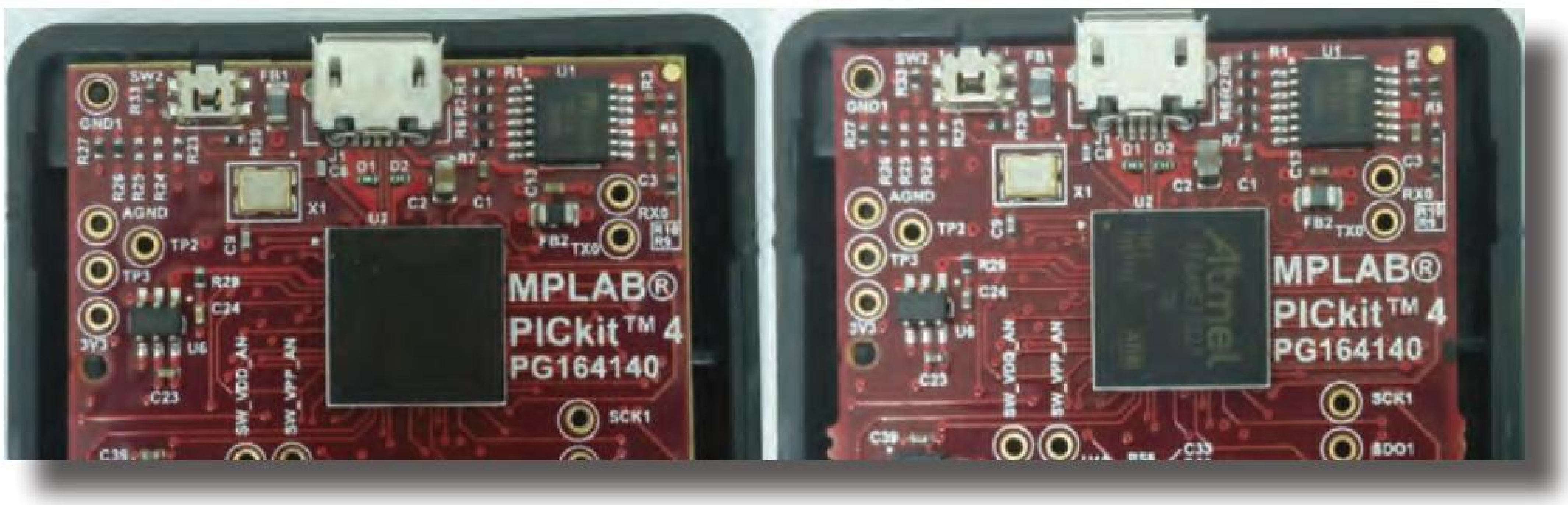


Fig.4. Side-by-side comparison of the PIC32CZ2038CA and ATSAME70Q21

Atmel 32-bit SAME70 300MHz ARM Cortex M7. An even tastier discovery is in a second 'identical' PICkit 4 I got my hands on, which uses a microcontroller labelled as the PIC32CZ2038CA – see Fig.4. There is no mention of the PIC32CZ anywhere in Microchip's documentation, so it looks like a re-branding of the SAME70 as a new line of PIC32CZ microcontrollers.

Microcontrollers aside, it's clear there has been a lot more development on the PICkit 4's PCB. Component size has been reduced to save PCB real estate in exchange for greater circuit protection on the inputs and outputs; there are more controlled voltage outputs; plus other additional functionality. Fig.5 shows the design complexity, including 7/8-bit quad digital potentiometers (MCP4452), protected power distribution switches (2042-1YTS) and quick-blow fuses on the connector pins.

Requirements

The PICkit 4 is supported by MPLAB X version 4.15 or later, but I recommend downloading the very latest version, which at the time of writing means v4.20. This is a 669MB download, available at: **www.microchip.com/mplabx**

The board in action

While most PICs and dsPICs are supported, they are currently only in preliminary beta support; any remaining PICs will be added as updates over the coming months. So, most devices should work, but there may be 'some issues'. It is recommended to use the micro-USB cable supplied with the programmer – there have been some early reports of problems with other USB cables. Why? – I don't know! But best to follow the manufacturer's advice for now.

While some features are not yet supported, they are promised in future updates. In saying that, there are a few hidden features that are not advertised. For example, previously, 'bricking' (rendering a device useless with a software upgrade) PICs by erasing the OSCCON could only be reversed by the PICkit 2 and this functionality was lost with the PICkit 3. This feature has now returned to help with some of the older PICs. I've tested this on a few bricked PIC10F200 devices and they are now running again – happy days!

It did take a little bit of work to get the PICkit 4 up and running, but once I succeeded it did run smoothly. The initial firmware update for the PICkit 4 was slow, after which it worked normally. One thing I noticed was the build/compile and program time was much faster than the PICkit 3.

Debugging

Debugging is of course a vital part of any PICkit system – so how did it perform? Mostly fine and as expected, but here are a few points worth highlighting. When running in debug mode, I forgot to select a breakpoint and when I selected a line to break on during normal run, the system didn't tell me it couldn't add breakpoints during operation (different to the PICkit 3). Instead, it paused at the selected break point. This is typically a feature for the ICD3 programmers. Stepping through the code was smooth, previous delays have been removed and it instantaneously jumps to the next line of code.

The PICkit 3 only allows two hardware breakpoints. When I selected more than two breakpoints with the PICkit 4 I was asked if I wanted to enable software breakpoints (another ICD3 feature). I was impressed at the user experience of this addition: instead of being told I need to enable them, leading to a lengthy search process, I was immediately given this handy software breakpoints option.

I was disappointed that the Programmer To Go function was not enabled yet. However, Microchip has confirmed this will be released as a software update that will allow the use of storing images on a microSD card, plus the ability to power the programmer from the target.

I tried out the supply target voltage feature and found I can manually change the target voltage with up to three decimal places of accuracy. I verified a few values with a multimeter, each time the value seemed to be off by about 166mV. I'm guessing that either my multimeter is off, or there was an unaccounted-for diode drop.

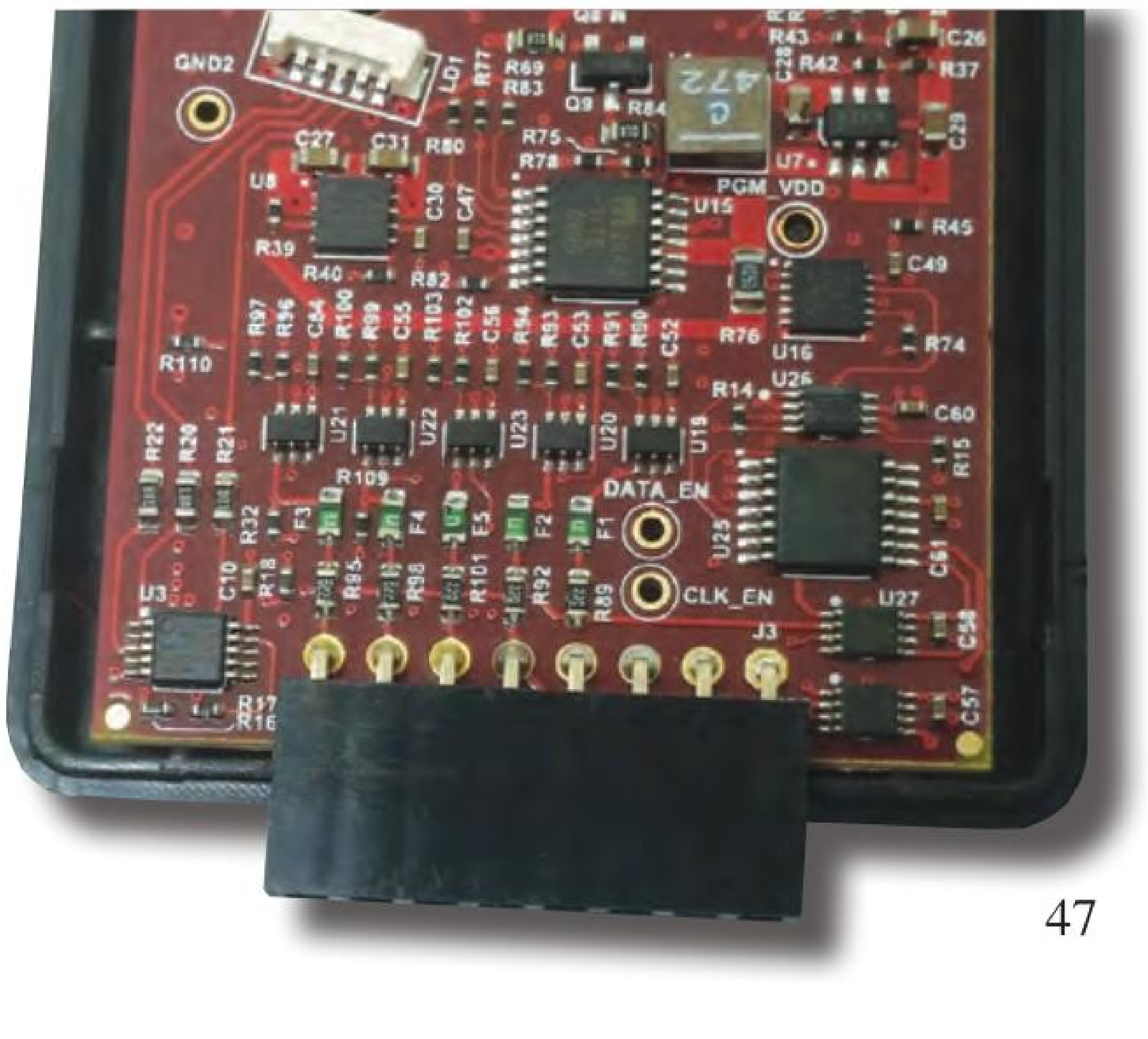
The target power menu in MPLAB X would not allow me to enter values outside the operating range of the PIC. For the PIC16F1829, it would only allow values between 2.3V and 5.0V. When I tried to program a PIC16LF1937, it gave me a range of 2.3V to 3.6V. I thought this was a nice little addition compared to the previous pop up asking if your device is 5.0V tolerant.

The PGC and PGD pins

The programming pins are now tri-stated after programming and released from reset. This means the PGC and PGD pins can be shared and used properly when powered by the programmer (excluding when they are used for debug purposes).

These pins can also be selected as pull-ups or pull-downs, and it is even possible to select the resistor value (in kΩ), with 50kΩ as the largest value.

Fig.5. Close up of the PICkit 4 protection circuits



Bricking the PICkit 4

While not ideal, it is worth knowing that it is possible to brick the PICkit 4. There is a small button beside the USB connector. If you press this, it will place the device into a recovery boot mode and the device will be unusable. To initiate device recovery, open the Debug menu in MPLAB X and select 'Hardware Tool Emergency Boot Firmware Recovery'. Follow the instructions precisely and your programmer will be back working again in a matter of minutes. Ideally, though, don't press the button!

The ICD4

Microchip's latest premium In-Circuit Debugger/Programmer – ICD4 – was released last year. It uses the same ATSAME70Q21 microcontroller, alongside a beefy Spartan6 FPGA with 2MB of SRAM, but it doesn't boast a fraction of the additional features of the PICkit 4. Considering it uses the same microcontroller, maybe these are features that will be added at the same time as the PICkit 4. We may do a review of the ICD4 at a later date, when more features of the PICkit 4 have been released.

Conclusion

While the PICkit 4 offers a lot more than the PICkit 3, it does seem like it was released a little prematurely – some aspects of it do feel unfinished. The majority of PICs and dsPICs are still in preliminary support and some of its ambitious features are not yet enabled, so don't discard your PICkit 3 or PICkit 2 just yet.

The additional features seem to be enabled through software upgrades of the MPLAB X IDE. So far, the changes that have been added show that there is a lot of thought going into this product, and once it is complete, it will be a serious market competitor with its ability to program not only PICs, but AVR, ARM and JTAG devices.

For more information on the PICkit 4, check out Microchip's website: **www.microchip.com/PICkit4**

Beginner's Guide follow-up

Starting in 2016, and finishing in 2017, I wrote a *Beginners Guide to PICs* using the Low Pin Count Demo (LPCD) board (DM164120-1) with the *PICKit 3 User Guide*. Unfortunately, the LPCD board is no longer manufactured and as stock is used up it has become difficult to obtain. This leaves a gaping hole for users wishing to start PIC programming and experimenting. There is no directly compatible board that can be used instead of the LPCD board. However, there are plenty of other demo and evaluation boards from Microchip that are great places to start, including the following:

- DM164140 – 8-bit PIC16F18855
- DM164141 – 8-bit PIC16F8345
- DM164142 – 8-bit PIC16F18877

While these are developed for use with the online MPLAB Xpress IDE (**www.microchip.com/mplab/mplab-xpress**), they are still nice starting points, that do not need external programmers or large downloads.

MPLAB Xpress incorporates the MPLAB Code Configurator, easing initialisation and application code for 8-bit, 16-bit PICs and dsPICs using a graphical interface and pin map. Unfortunately, these small development boards all use tiny QFN-packaged microcontrollers, which don't lend themselves to making your own custom bread-board designs.

While there is no straightforward replacement for the LPCD board, the 8-bit Curiosity Development Board in Fig.6 (DM164137) is the closest. It contains a lot of the same features as the LPCD board, including LEDs, potentiometer and a button. It uses the PIC16F1619, which has a similar feature set to the PIC16F1829 in the LPCD board. The Curiosity development board includes its own programmer/debugger and requires no additional hardware to get started.

The Curiosity Development boards come in 8-bit and 16-bit variants that still use classic DIP (dual inline package) socket microcontrollers, which can be easily removed by hand. DIP microcontrollers are ideal for jumping into PIC programming and building your own custom designs very quickly and are therefore more popular for bread-boarding projects and rapid prototyping.

Despite the demise of the LPCD board, much of the *Beginner's Guide* information is still relevant and useful, but do note that many details including pin numbers and internal operations will be different if you transfer to the Curiosity system. Also note that the Curiosity Demo Code provided on Microchip's website contains a ReadMe PDF that details the very same lessons covered in the *Beginner's Guide*, see:
www.microchip.com/DevelopmentTools/ProductDetails/DM164137

A nice bonus with the Curiosity board is that it has a mikroBus connector, allowing the easy addition of a module like the RN4020 with Bluetooth Low Energy communication. A large number of Microchip's development and evaluation boards support mikroElectronika's mikroBus Adapter click boards. These come in a standard size that simply 'click' into their mikroBus headers, allowing the addition of all sorts of additional functionality from temperature/pressure sensors and heart rate monitors to brushless motor controllers, audio speakers/microphones and even displays. The mikroBus provide a very simple and effective interface to connect a great variety of devices.

Next month

The PICkit 4 has great potential as a programmer if it lives up to its ambitions and Microchip irons out all the bugs. Despite the current limitations, I do recommend picking one up – like a fine wine, it will get better with time!

Following the popularity of the dsPIC articles by Mike Hibbett, we will soon be starting an explorative series of articles that will slowly grow from some simple features into a much larger project. We will look at how to manage a growing project, how to catch potential problems early on and how to allow for design growth. We'll start with a breadboard design and convert it to a PCB when we're ready to start building permanent hardware. The main goal is to create a realistic digital multimeter that can measure a useful range of voltage, current, impedance, frequency and other features.

Not all of Mike's technology tinkering and discussions make it to print.

You can follow the rest of it on Twitter at *@MikePOKeeffe*,

on the *EPE Chat Zone* or *EEWeb's* forums as *'mikepokeeffe'* and from his blog at *mikepokeeffe.blogspot.com*

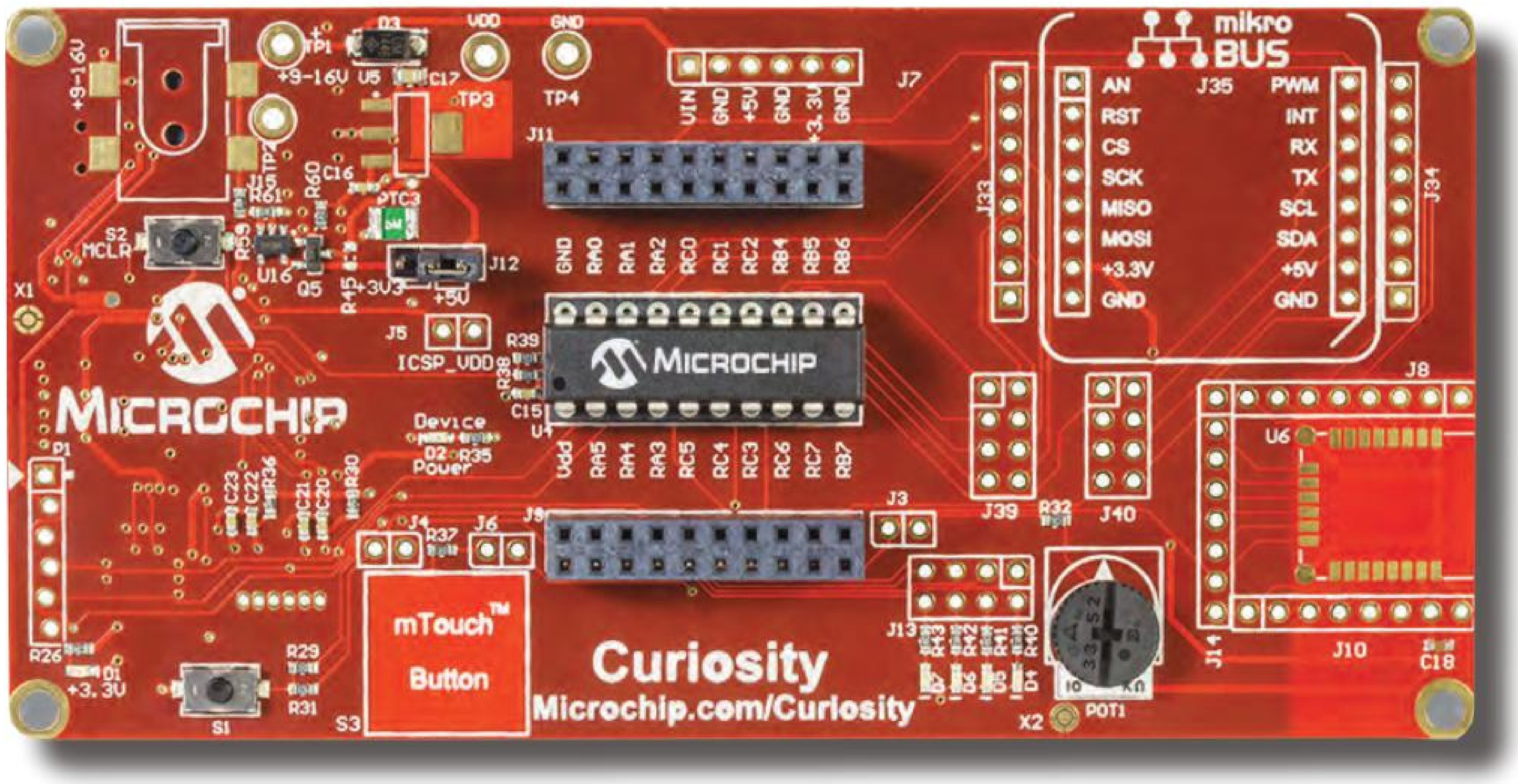


Fig.6. Curiosity Development Board (DM164137)

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The MPLAB PICkit 4 In-Circuit Debugger/Programmer allows fast and easy debugging and programming of PIC and dsPIC Flash microcontrollers, using the powerful graphical user interface of MPLAB X Integrated Development Environment (IDE), version 4.15. The MPLAB PICkit 4 is connected to the design engineer's computer using a high-speed 2.0 USB interface and can be connected to the target via an 8-pin single in-line (SIL) connector. The connector uses two device I/O pins and the reset line to implement in-circuit debugging and In-Circuit Serial Programming (ICSP). An additional micro SD card slot and the ability to be self-powered from the target means you can take your code with you and program on the go.*

The MPLAB PICkit 4 programs faster than its predecessor, using a powerful 32-bit 300MHz SAME70 MCU, and comes ready to support PIC and dsPIC MCU devices. Along with a wider target voltage, the PICkit 4 supports advanced interfaces such as 4-wire JTAG and Serial Wire Debug with streaming Data Gateway, while being backward compatible for demo boards, headers and target systems using 2-wire JTAG and ICSP. The PICkit 4 also has a unique programmer-to-go function with the addition of a micro SD card slot to hold project code and the ability to be powered by the target board.

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BY IAN BELL

Analysing a summing differentiator circuit

REGULAR readers will know that *EPE* has its own tag 'EPE Magazine' on the EEWeb forum (**www.eeweb.com/forum**). There are many interesting questions and answers, and the majority of relevant questions receive at least one reply from one of EPEWeb's resident experts. A few weeks ago a question from Michele Oliva caught my eye – it was titled 'Help with Op-amp Differentiator Circuit', but the schematic showed something that was not quite a standard differentiator amplifier – because it had two inputs (see Fig.1). As was pointed out by David Ashton, the EEWeb expert who replied, it is like a summing amplifier. This is true, but again it is not quite a standard op amp 'summing' configuration.

This month, we will look at the posted question related to this circuit, which is really about analysing the voltages around the two sources – not differentiator operation. We will take a very detailed look at this (although it is not strictly necessary to do so to provide an answer). Our analysis will serve to illustrate the use of a few circuit theory techniques, showing how we can sometimes perform simplified calculations and get the right answer – for example, by ignoring certain components or effects – whereas other times we need a more comprehensive calculation. Checking simplifications are valid after using them is an important part of this approach. We will also simulate the circuit, but as we will see, the original forum post does not provide all the parameters we need, so the results of our calculations are needed here. Differentiator and summing op amp circuits more generally are interesting circuits, so we may return to this topic in a later article.

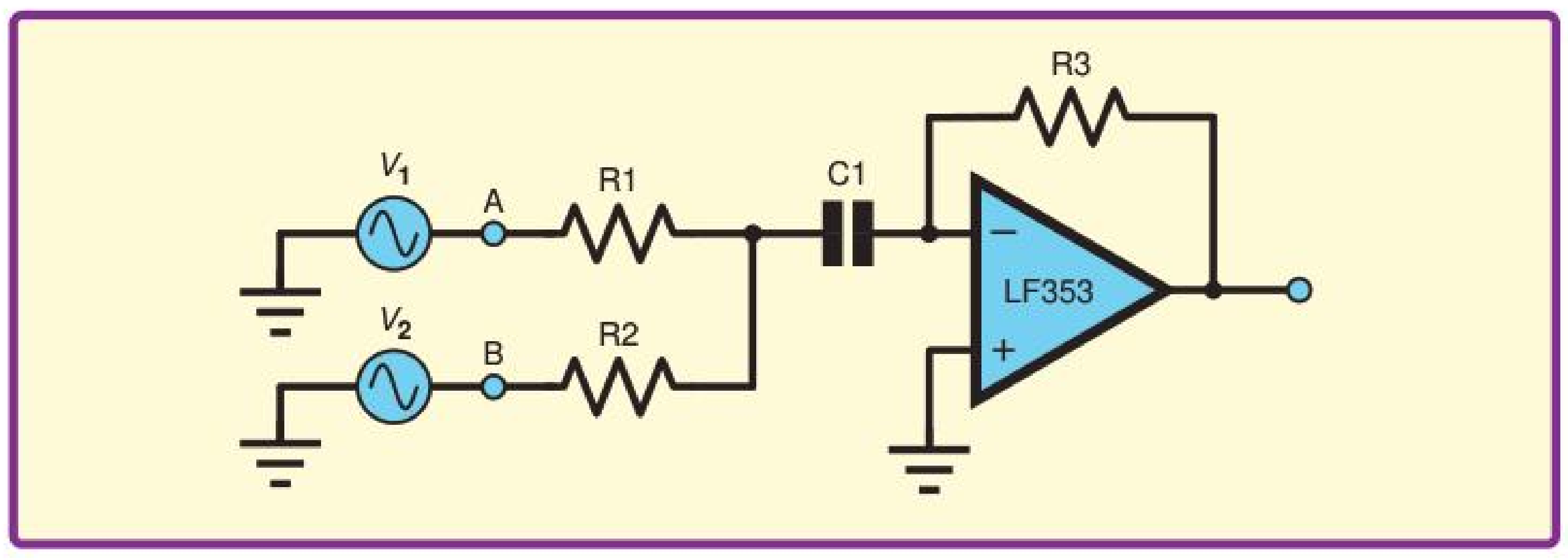

Fig.1. Michele Oliva's circuit from EEWeb Forum (with some edits to labelling).

Michele wrote, 'I have Fig.1 with:

$R_1 = R_2 = 1\text{k}\Omega$
$R_3 = 10\text{k}\Omega$
$C_1 = 100\text{nF}$
V_1 generates a sine with amplitude = 5V and frequency = 160Hz
V_2 generates a sine with amplitude = 100mV and frequency = 16000Hz

Why in B do I see a contribution of the first input, but in A I do not see a contribution of the second? In A, I see Fig.2, and in B, I see Fig.3. How can I solve this problem?' (Note: we made some edits to component labels.)

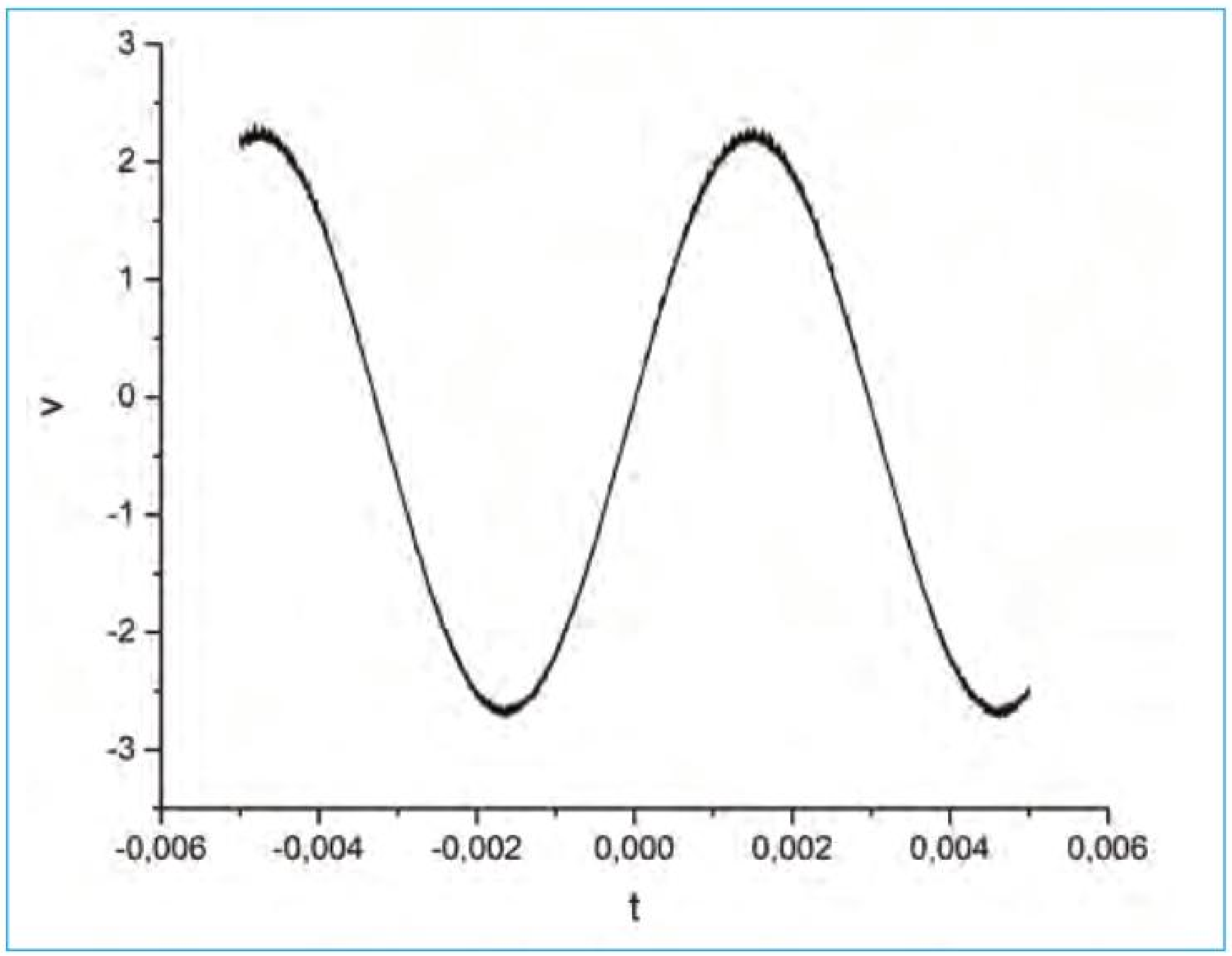

Fig.2 . Waveform at point A in the schematic in Fig.1 (from EEWeb Forum).

Waveforms and sources

The waveform at A in Fig.1, the output of the V_1 source, is shown in Fig.2. It is a 160Hz sinewave of $5\text{V}_{\text{pk-pk}}$ (peak-to-peak) amplitude with some noise evident on it, but no obvious sign of the 16kHz signal from source V_2. The waveform at B in Fig.1, the output of the V_2 source, is shown in Fig.3. This clearly contains contributions from both the 160Hz and 16kHz signals. In fact, the two sinewaves have similar amplitudes; about $120\text{mV}_{\text{pk-pk}}$ for the 160Hz signal, and about $100\text{mV}_{\text{pk-pk}}$ for the 16kHz signal. The noise on both waveforms indicates they were probably captured from an oscilloscope rather than produced by a simulator.

The simple answer to why we see the influence of V_1 at B, but not V_2 at A is the relative magnitude of the two sources (V_1's amplitude is 50 times that of V_2). However, we can look at this in more detail, both calculating and simulating to find, and verify, values consistent with Fig.2 and Fig.3. One thought that might occur at this point, particularly if you assumed that the sources are ideal, or have low output impedance, is that there should be little or no sign of the signal from V_1 at B. Clearly there is, and the conclusion has to be that the sources are not 'very low impedance'. If the sources were ideal, then the signal at B would be a pure $100\text{mV}_{\text{pk-pk}}$, 16kHz sinewave.

Neither the schematic, nor the details in the question text, tell us what the source impedance is; however, from the circuit and the waveforms in Fig.3 we can use a little circuit theory to estimate the value. We start by simplifying things – this is often a good strategy to reduce calculation effort, but a check should be made, once we have a result, that the simplification was valid.

Superposition and simplification

The first bit of circuit theory we need is the principle of superposition (or the 'superposition theorem'). This can be stated as the total voltage (or current) in any part of a linear circuit equals the algebraic sum of the voltages (or

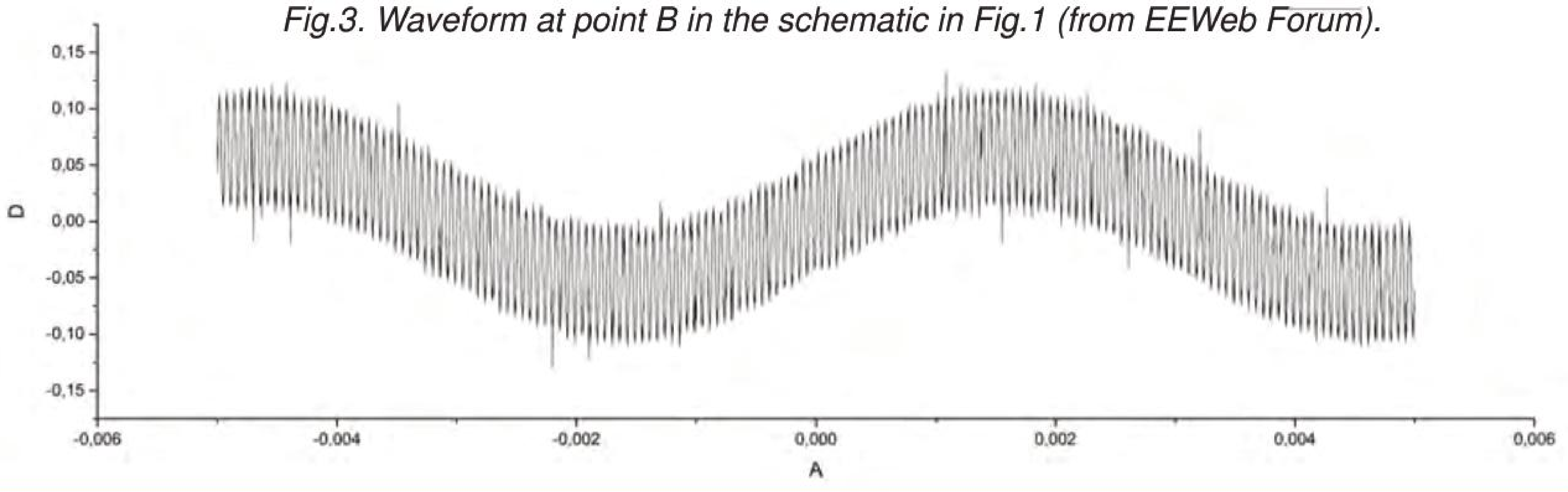

Fig.3. Waveform at point B in the schematic in Fig.1 (from EEWeb Forum).

currents) produced by each source separately. This means we can analyse the circuit with respect to each source individually, setting the other sources to zero, and then add up the results. If the sources have internal resistance, or output resistance (whatever term is preferred), then this should be included if it will have a significant impact on the result. The circuit must be linear for this to work – so resistors are fine, but if nonlinear devices like diodes are present, then we can't' do this. For the circuit in Fig.1, using superposition means we can set $V_2 = 0$ and find the voltage at B just due to V_1 (and then *vice versa*).

Next, we consider the simplifications we can make. The reactance (AC 'resistance') of a capacitor, of value C, at frequency f, is given by:

$$X_C = \frac{1}{2\pi f C}$$

This is about 10kΩ (9.947kΩ) for the 100nF capacitor C_1 at 160Hz. This is significantly larger than the 1kΩ resistors, so we should be able to ignore it for an approximate calculation. However, the capacitor has reactance, *not resistance*, so we should check its effect more precisely later.

Removing C_1 reduces our circuit of interest to just the two resistors connected between the sources (see Fig.4). We do not know the source resistances (R_{S1} and R_{S2}), but we will assume they are the same and that they are significantly less than 1kΩ (this will need checking later). Since R_{S1} is in series with R_1 and R_2 we will initially ignore R_{S1} and combine R_1 and R_2 into a single 2kΩ resistor, R_T. Using superposition we can set V_2 to zero (so we are just looking at the contribution to V_B from V_1). This simplifies the circuit in Fig.4 to the basic potential divider shown in Fig.5.

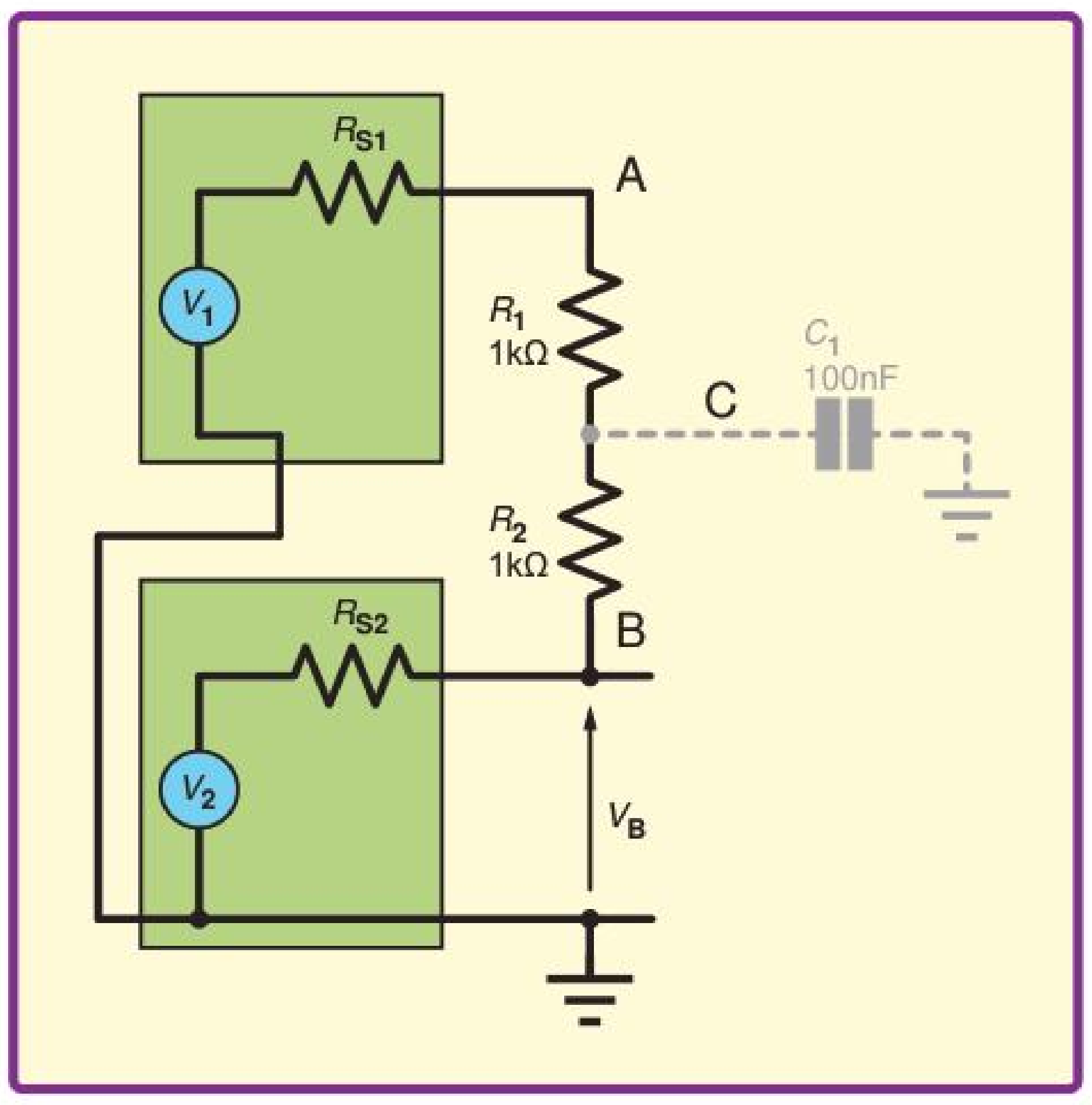

Fig.4. Resistors and sources from Fig.1, with source internal resistance shown.

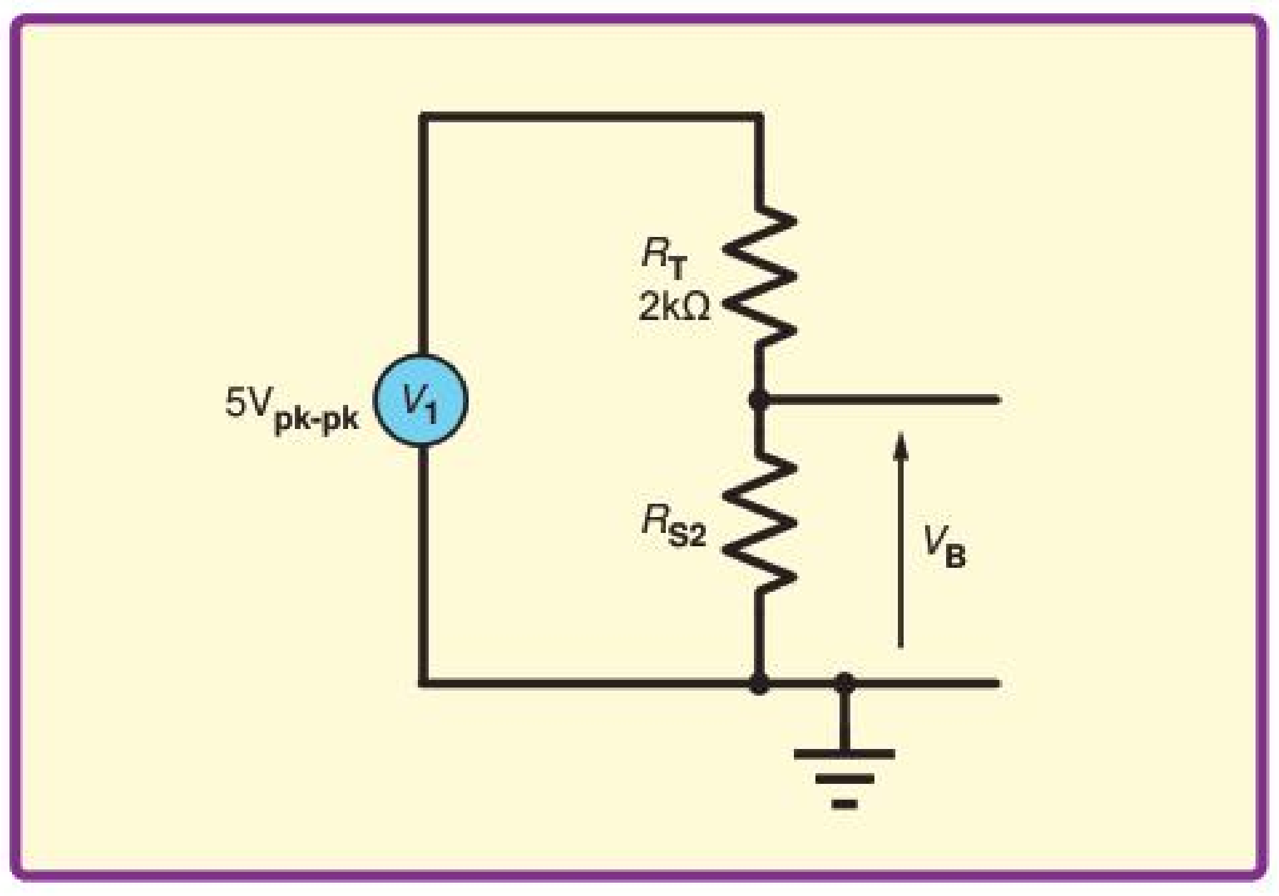

Fig.5. Circuit in Fig.4 simplified to a basic potential divider for finding the contribution to V_B from V_1.

Potential divider

We can apply the potential divider formula to the circuit in Fig.5:

$$V_B = \left(\frac{R_{S2}}{R_T + R_{S2}}\right) V_1$$

We know V_B (120mV from Fig.3), but R_{S2} is unknown, so we rearrange this equation to find R_{S2}:

$$R_{S2} = \frac{R_T V_B}{V_1 - V_B} = \frac{2000 \times 0.12}{5 - 0.12} = 49.2$$

This makes sense because it is common for signal generators to have an option to set a 50Ω output impedance for matching purposes (eg, to 50Ω coax). It seems likely that both sources have a 50Ω output impedance; however, we should still check that out assumptions are valid.

The result of 50Ω validates our assumption that the source resistance is much less than 1kΩ. Also if we assume the same value for R_{S1} and apply the potential divider equation for V_B (above) with R_T = 2100Ω we do not get a significant shift in V_B (119mV) – we cannot easily measure V_B that accurately from Fig.3, but it is still in the right range.

We do not really know if the voltage quoted for V_1 (5V) is the actual source voltage or measured output, but if we assume it is the source internal voltage. With the internal resistance of 50Ω and a load of 2050Ω (the two 1kΩ resistors and the V_2 source impedance) the actual output at point A will be 4.88V (from 5 × 2050/2100 in the potential divider formula), which is consistent with the signal shown in Fig.2.

The capacitor

So far, we have ignored the 100nF capacitor (C_1) on the assumption that it has little effect on a 160Hz signal. Looking at Fig.4 again, now that we know the source resistances are 50Ω, we can redraw this circuit to look at the effect of C_1 on the voltage at point C (where the capacitor is connected) – see Fig.6. We are still using superposition to consider just the effect of V_1 alone (ie, V_2 is set to 0V). If, in this scenario, the presence, or not, of C_1 changed the voltage at point C significantly, we may have to revise our previously calculated value for V_B.

In Fig.4 and Fig.6, C_1 is shown connected to ground, whereas in Fig.1 it is connected to the op amp's inverting input. In fact, this point in the circuit is known as virtual earth (or virtual ground). It isn't actually connected to ground, but behaves very much like a ground connection in that it remains more or less at 0V all the time. This is an approximation, which we will discuss in more detail later.

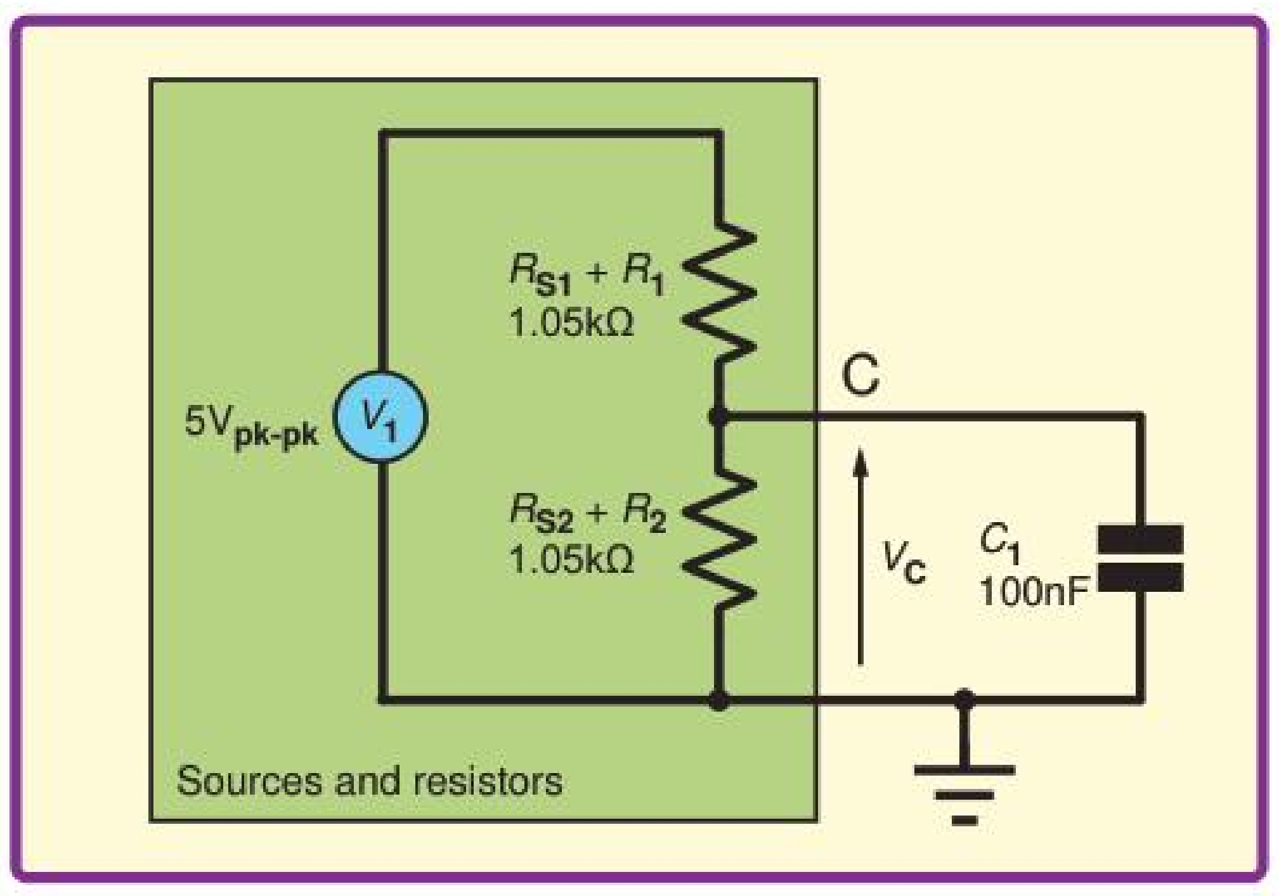

Fig.6. Circuit in Fig.4 redrawn to consider the effect of C_1.

Thévenin

One way to approach analysing the circuit in Fig.6 is to find the Thévenin equivalent of the circuitry in the 'sources and resistors' box. Thévenin's theorem states that a linear circuit with two terminals (outputs) containing several sources and resistances can be replaced by a single voltage source in series with a single resistor. To obtain the Thévenin equivalent for any suitable circuit we find the open circuit output voltage and then the short-circuit output current. The open-circuit voltage is used as the equivalent source voltage (V_{TH}) and the open-circuit voltage divided by the short-circuit current gives the source resistance (R_{TH}).

For our circuit, the open-circuit output voltage (ie, at C without C_1

connected) is half V_1 (V_{TH} = 2.5V$_{pk-pk}$) because the circuit in the box is a potential divider with two equal resistors. The short-circuit current (that is with point *C* shorted to ground) is 5V / 1.05kΩ = 4.76mA. The Thévenin source resistance is therefore R_{TH} = 2.5V/4.76mA = 525Ω. Replacing the circuit in the sources and resistors box in Fig.6 with its Thévenin equivalent leads us to the circuit in Fig.7.

The circuit in Fig.7 is immediately recognisable as a basic RC low-pass filter (with input V_{TH} and output at *C*). The cut-off frequency (*fc*) of an RC filter is given by:

$$f_c = \frac{1}{2\pi RC}$$

For this circuit, f_c is about 3kHz. Thus, at 160Hz (more than a decade lower in frequency) we would not expect much attenuation of the voltage at C (it will be almost equal to V_{TH}), and we can infer that connecting C_1 to point C in Fig.1 will not shift the voltage at C due to V_1 by very much, which in turn means that V_B will not be affected.

Reactance

The circuit in Fig.7 is also a potential divider. Earlier, we found that the capacitor C_1 had a reactance of about 10kΩ; however, because this is reactance, not resistance, we cannot simply put 10kΩ and 525Ω into the resistor potential divider formula above to find the voltage at C. A full analysis requires use of complex numbers, or phase and magnitude vectors. Here though, we are just interested in the voltage amplitude, not the phase, so we can keep things relatively simple and just consider magnitudes.

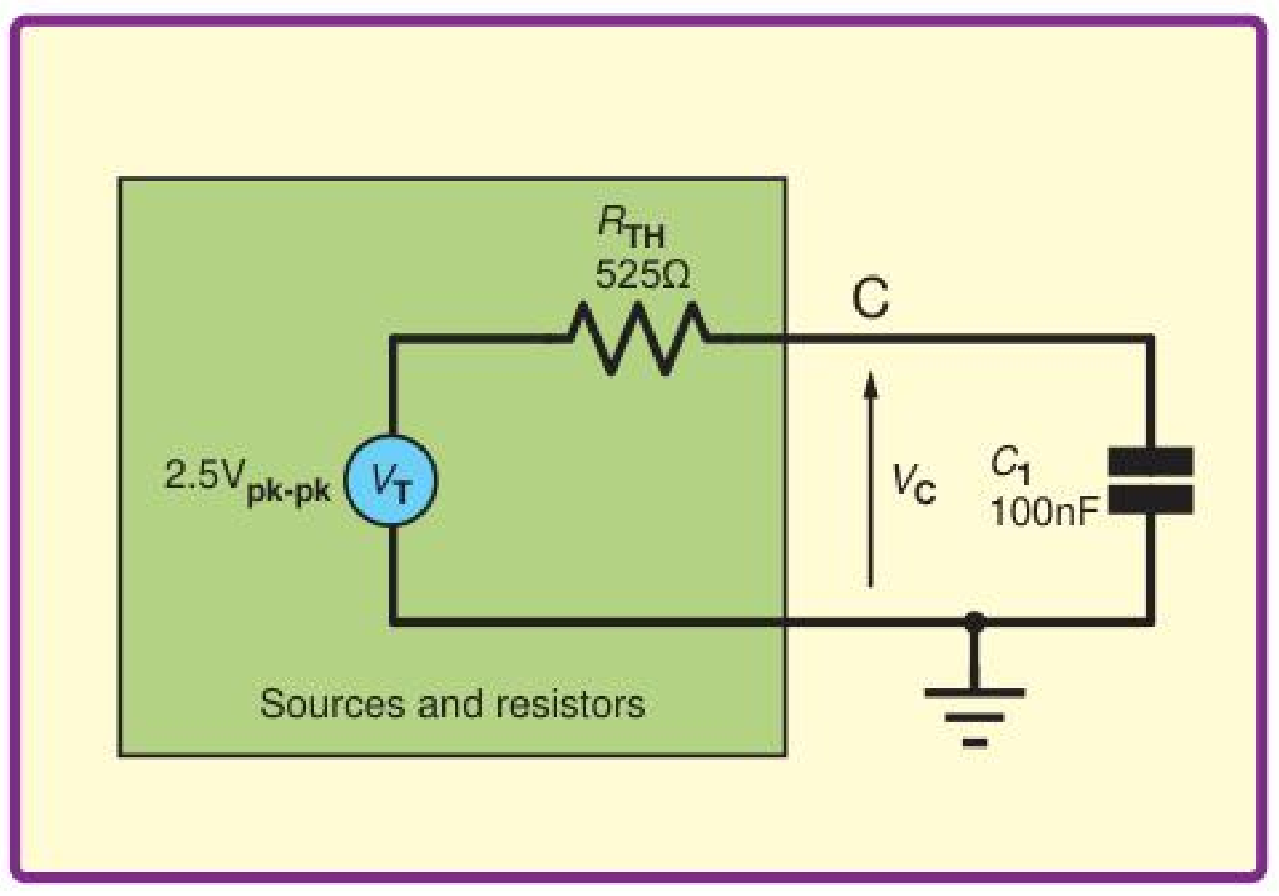

Fig.7. Circuit in Fig.6 using Thévenin equivalent for the 'sources and resistors' part of the circuit.

To find the voltage at point C we can find the current flowing through R_{TH} and C_1 and then use this to obtain the voltage across C_1. The resistor and capacitor connected from V_{TH} to ground in Fig.7 form an impedance – that is, together they have both resistance (R_{TH}) and reactance (X_C). The magnitude of this impedance is given by:

$$Z = \sqrt{R_{TH}^2 + X_C^2}$$

Strictly speaking, X_C is a complex number, involving the square root of minus one, but squaring it to obtain the magnitude gives us an ordinary ('real') number. To find the current magnitude we divide the applied voltage by the impedance magnitude (Ohm's law). We then multiply this current by the reactance of C_1 – or more correctly, the *magnitude* of X_C, given by $\sqrt{(X_C^2)}$ – to get the magnitude of the voltage at point C. This gives us a potential divider equation for our RC low-pass circuit:

$$V_C = \left(\frac{X_C}{\sqrt{R_{TH}^2 + X_C^2}}\right) V_{TH}$$

Using the value from Fig.7 gives V_C = 0.9986V_{TH} (at 160Hz). So we conclude that C_1 has very little effect on the voltage at C with respect to the 160Hz signal – so ignoring it earlier was valid.

Having checked that most of our assumptions and approximations look correct (we will come back to the virtual earth) we can conclude that the we are happy with the result that the source impedances are 50Ω and this results in a 119mV$_{pk-pk}$ 160Hz signal at point B, as shown in Fig.3, and a 4.88V 160Hz signal at point A, as shown in Fig.2.

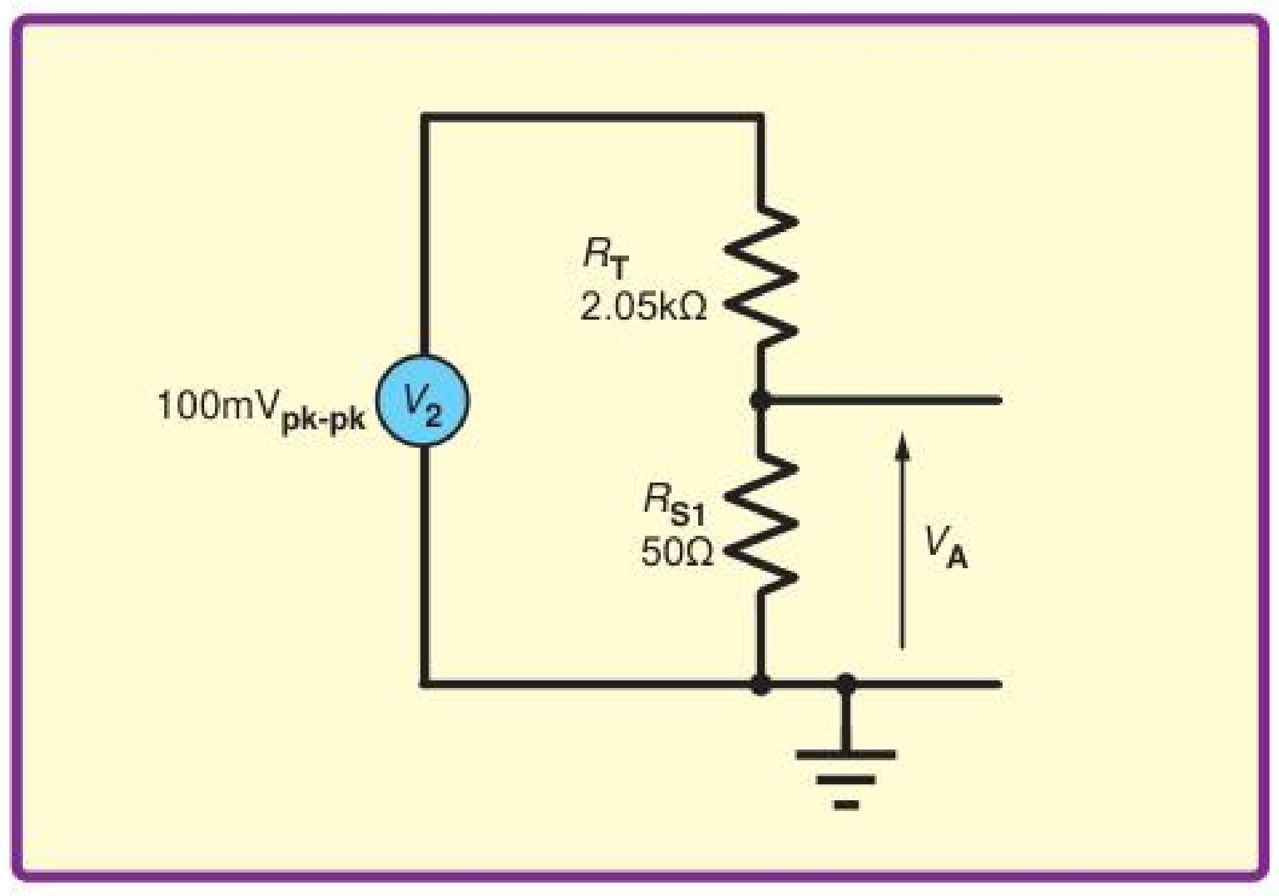

Fig.8. Circuit in Fig.4 simplified to a basic potential divider for finding the contribution to V_A *from* V_2.

Signals at A

We can use a similar approach to find the signal at point A due to the 100mV source, V_2. We set V_1 = 0 in Fig.4 (ignoring C_1 again for the moment), assume both source resistances are 50Ω and redraw a simplified equivalent circuit, similar to Fig.5, as shown in Fig.8. Since we know both resistances this time, we can immediately apply the potential divider formula implying: V_A = 0.1 × 50/(50 + 2050) = 2.38mV$_{pk-pk}$ (at 16kHz). In the full circuit this will be on top of the 5V 160Hz signal from V_2.

When considering the signal from V_1 we found that the capacitor C_1 had a minimal effect. For V_2, our equivalent circuit will be the same as Fig.7, except with V_{TH} = 50mV$_{pk-pk}$. The signal frequency is now 16kHz, which is some way *beyond* the cut-off frequency of the RC low-pass filter. We would therefore expect C_1 to have a significant effect on the voltage at point C for the 16kHz signal from V_2.

The reactance of C_1 at 16kHz is 99.5Ω. Using this in the RC low-pass potential divider equation we get V_C = 0.186V_{TH} = 9.31mV. The voltage at V_C for the 16kHz signal is significantly reduced by the presence of C_1 – we cannot ignore C_1 as we did with the 160Hz signal. The previously calculated value of 2.38mV is not going to be correct.

To find a more accurate value for V_A we note that the 9.31mV at C is across a resistor potential divider comprising 1kΩ and 50Ω, so the voltage at A is 9.31mV × 50 / (50+1000) = 443μV$_{pk-pk}$ due to V_2. This is about 11,000 times smaller in amplitude than the 4.88V signal at A, which explains why we do not see the 16kHz signal in Fig.2. The image posted on EEWeb has about 1300 pixels over the 5V of the sinewave, so the 16kHz signal would only occupy about a tenth of a pixel in the image – definitely not visible.

The capacitor will also affect the voltage of the 16kHz at the output of the V_2 source (point B) – it imposes a load along with the resistors. If we assume 100mV – 9.31mV. Across the 1kΩ resistor, plus 50Ω source impedance between point B and the V_2 source (Fig.4), then using the potential divider formula we get 87.4mV across the 1kΩ resistor, so a total voltage of 95.7mV at point B.

Virtual earth

We need to consider the virtual earth mentioned earlier. The circuit in Fig.9 is a standard inverting op amp amplifier. By virtue of the op amp's very high open-loop gain, the inverting input must be at a voltage close to zero if the output is not to be saturated (at a power-supply-limited maximum value). Thus the inverting input behaves as if it is connected to ground.

The op amp amplifies the voltage difference between its two inputs by its open-loop gain, whatever the values of the input and feedback resistor. The resistors can set the *circuit* gain (V_O/V_I) to different values, but the relationship directly between the op amp's inputs and output is fixed at its open-loop gain when operating normally. Consider an op amp with a gain of one million. If the output is at say V_O = 10V, then V_E will be 10μV, (10/1,000,000). If V_{IN} is more than a few millivolts then V_E can be reasonably approximated to zero without, for example, resulting in a significant error in calculating I_{IN}, the current in R_{IN}. In the circuit in Fig.1 it is reasonable to assume the capacitor is connected to a virtual earth.

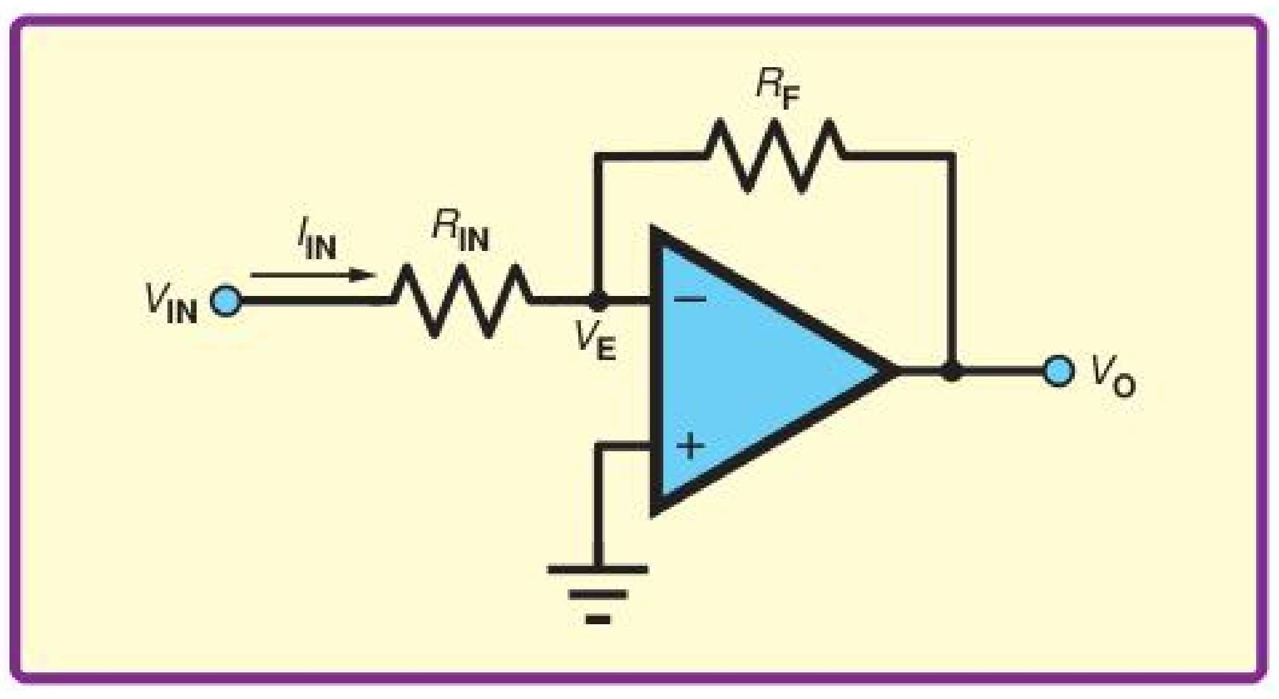

Fig.9. Op amp amplifier for modelling virtual earth, V_E.

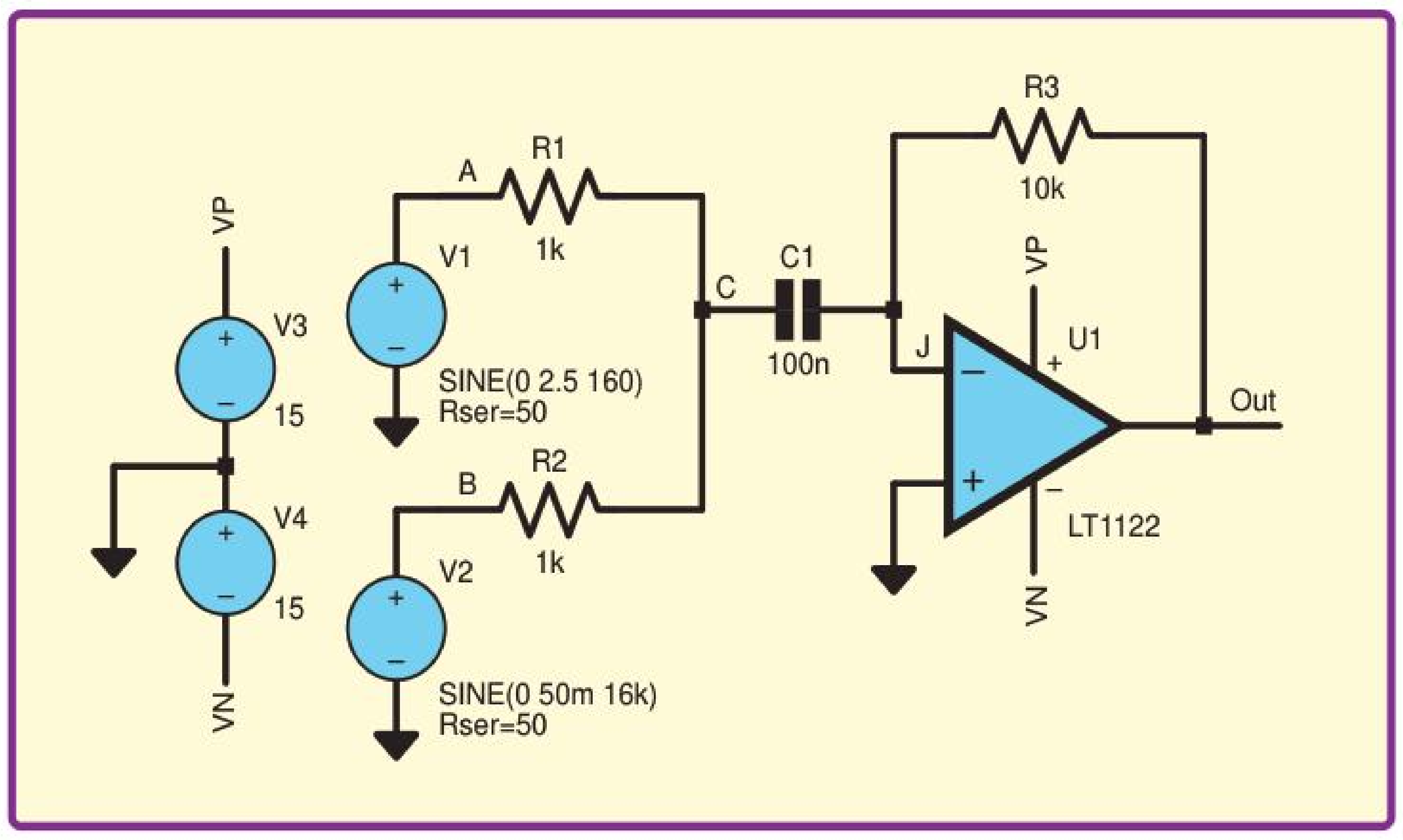

Fig.10. LTSpice schematic for simulation of the circuit in Fig.1 (LF353 replaced by LT1122).

Simulation

We can also simulate the circuit to see if we obtain waveforms similar to the measured signals, and signal levels which match our calculations. A schematic for simulating the circuit in Fig.1 in LTSpice is shown in Fig.10. The voltages specified for the sources are 2.5V and 50mV, not 5V and 100mV – this is because LTspice sinewave source voltages are specified using peak, not peak-to-peak values. The 50Ω source resistances are not shown as resistors on the schematic, but are included as a parameter for the sources (*Rser*=50).

The op amp was changed to an LT1122 (from Analog Devices) simply because it is available in the standard LTspice library, unlike the LF353. LTspice was originally developed by Linear Technology (LT), which is now part of Analog Devices. The simulator is available as a free download from Analog Devices' website, and, as might be expected, models are provided for LT and Analog Devices op amps as part of the download. The LF353, from Texas Instruments, is described as a wide-bandwidth JFET-input operational amplifier. The LT1122 was not chosen with a great deal of care – the op amp does not play a very significant role in our discussions – but it is another JFET-input device, found by scrolling through the library. It is described as a fast-settling, JFET-input operational amplifier and has 'high speed integrators' listed as a typical application on its datasheet – so it seemed suitable.

The results – showing waveforms at points A and B are shown in Fig.11 and indicate a good match with Fig.2 and Fig.3. Using the waveform measurement tools in LTspice on the results shown in Fig.11 it is possible to confirm the signal levels calculated above:

95.4mV, 16kHz and 119mV, 160Hz signal at B
4.88V 160Hz signal at A

The 16kHz signal at A can just about seen at high zoom, but is difficult to measure. We can simulate using the approach from our calculations with V_1 set to 0V. This makes the 16kHz signal at A easier to measure. Running the simulation with the capacitor grounded, as in our calculations, rather than connected to the op amp gave a voltage of 443μV$_{\text{pk-pk}}$. With C_1 connected to the op amp the voltage dropped to 389μV, showing the not-totally perfect virtual earth from the op amp can affect the circuit, but in this case the effect is not significant.

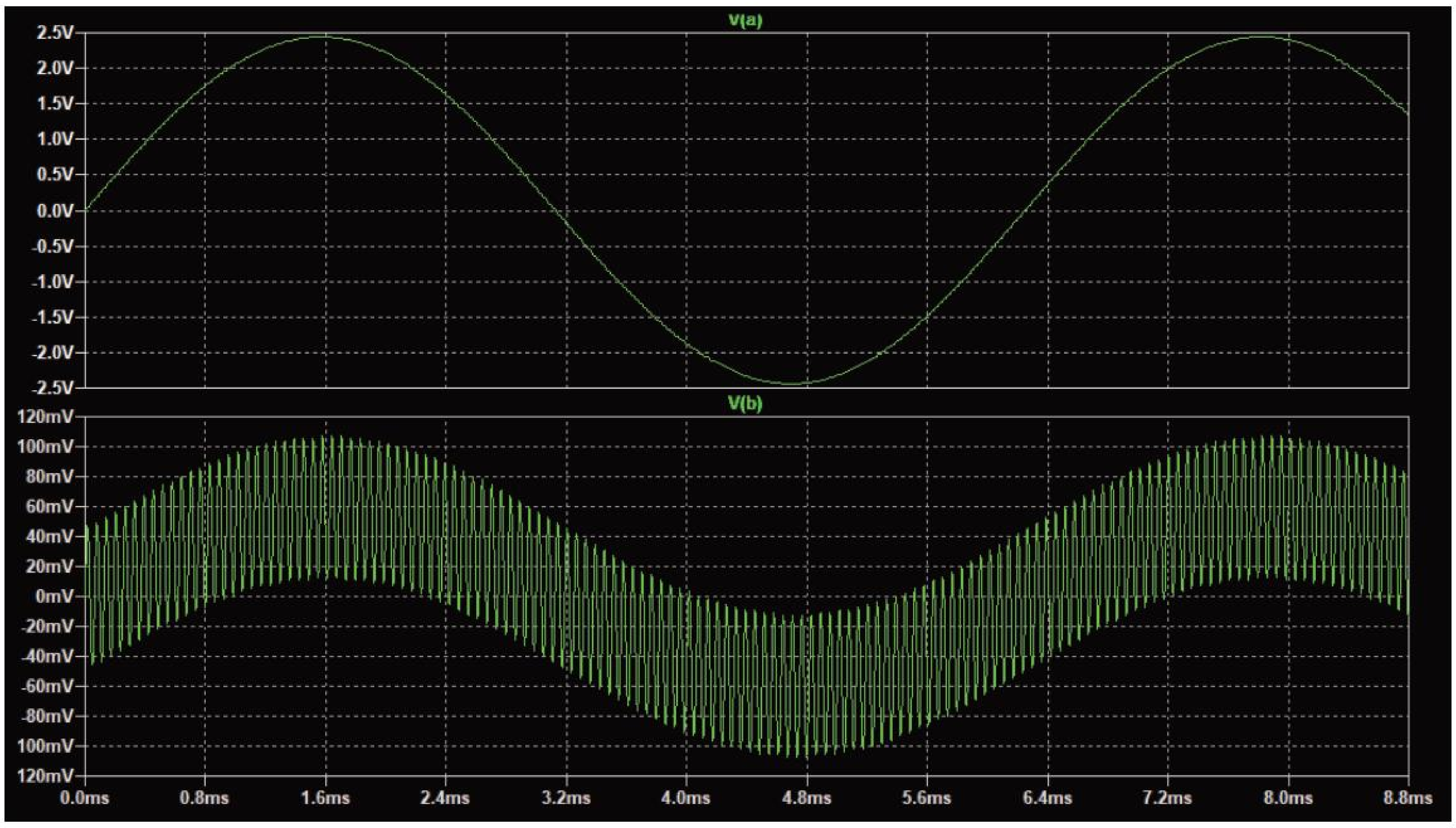

Fig.11. LTspice simulation of results showing similar waveforms to Fig.2 and Fig.3.

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AUDIO OUT

By Jake Rothman

Analogue synthesis – Part 1

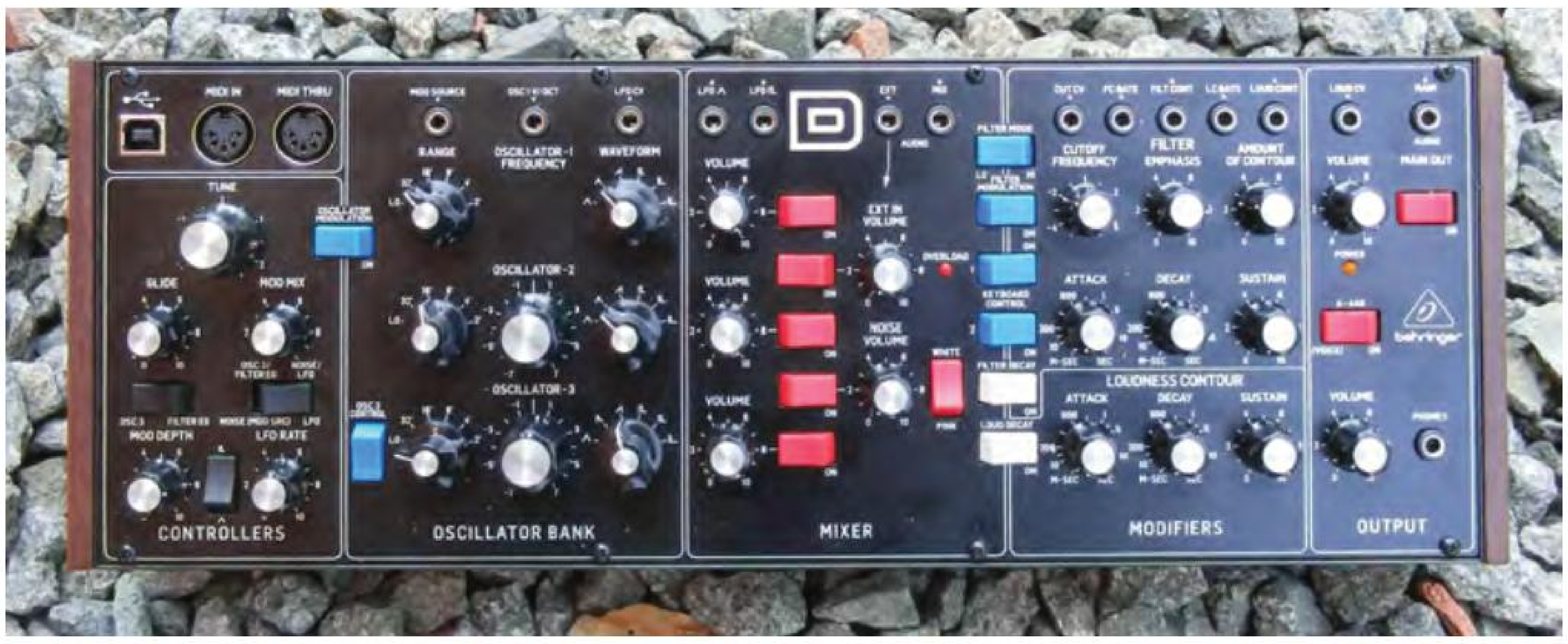
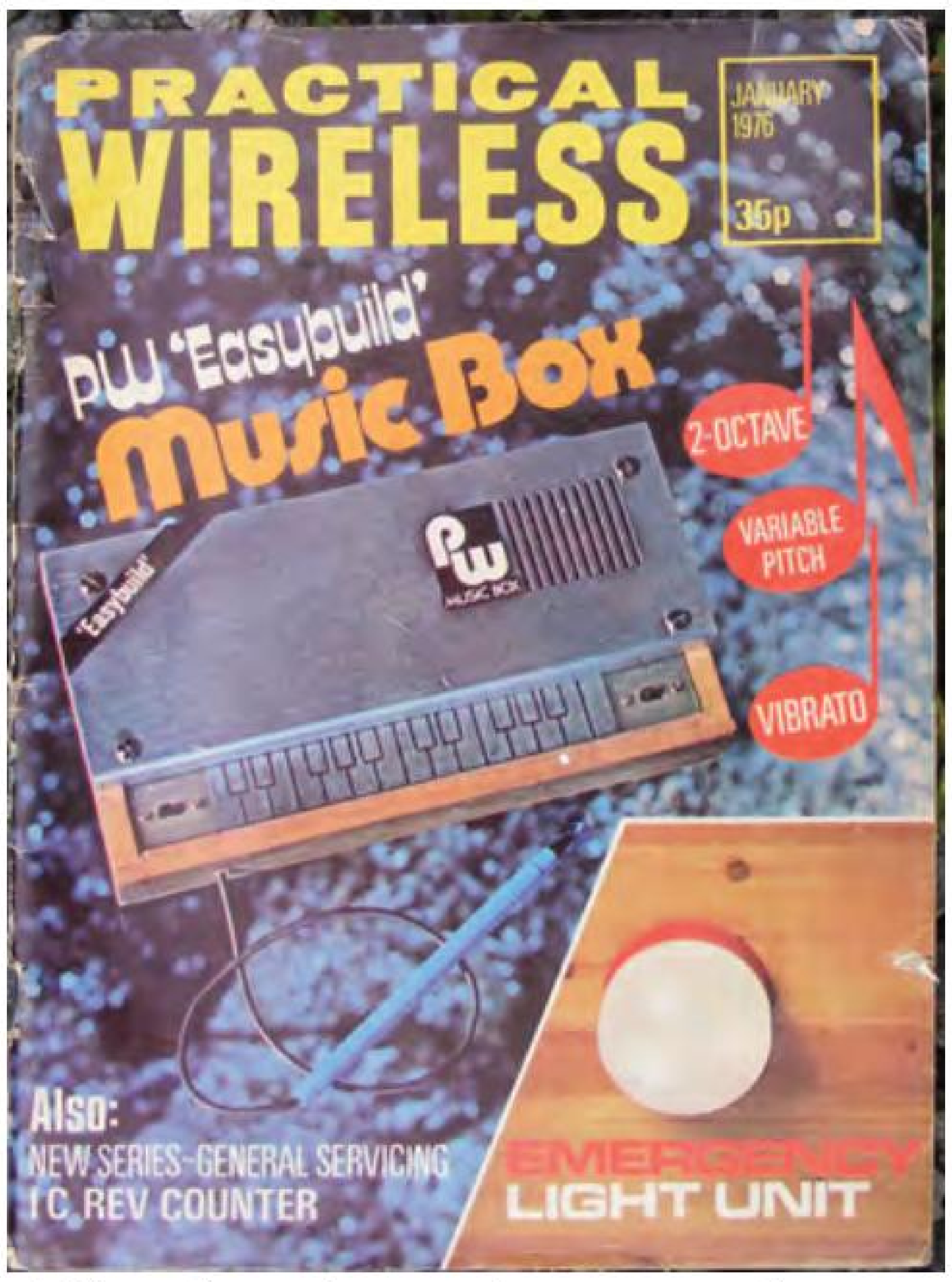


Fig.1. The Behringer Model D, a Chinese-built UK-designed clone of the Minimoog. It costs £300, rather than the 'collector' price of £4000 for the original.

Over the last few years I've written a great deal about processing audio signals in *Audio Out*. Now a radical departure – it's time to start *generating* audio signals. The best place for an electronics person to start on this path is analogue synthesis, using the techniques pioneered by Robert Moog. Old analogue 'synths', such as those from Roland, can attract eye-watering collector prices, but analogue synthesis doesn't have to be expensive and for once in electronics, home construction can save a fortune. The high prices for original collectible equipment have spurred manufacturers such as Behringer to make clones – for example, the Moog-inspired Model D shown in Fig.1.



A blast from the past! – my very first music project – the Music Box *from* Practical Wireless *in 1976.*

Of course, one might ask, why not sample acoustic signals or use a complex digital audio workstation with menu-based synths? This is how you simulate a piano or orchestra, but if you are driven to create original sounds and are inspired by the immediately available audible changes via knobs and circuits, then analogue is definitely the way to go. This is evident in the huge revival in analogue synthesis that has taken place over the last 20 years. One only has to look at the resurgence of analogue synthesiser modules popularised by Doepfer (Fig.2) or the late Ray Wilson with his *Music From Outer Space* circuits. These can be found in his book *Analog Sythesizers*, and *EPE* will be presenting some of these in conjunction with Soundtronics after this series. If you want to see Wilson's circuits in action, then watch Paddy Steer at: **https://youtu.be/r5n-XQgnH18**

Some of the most famous analogue synth music was created in the 1970s. My favourite example of the use of the Moog synthesiser is Stevie Wonder's album *Talking Book*. Kraftwerk's *Autobahn* and *Oxygene* by Jean-Michel Jarre are further examples of pure analogue synthesis.

Analogue sound and the Stylophone

Most electronic engineers of my generation are familiar with the cheap,

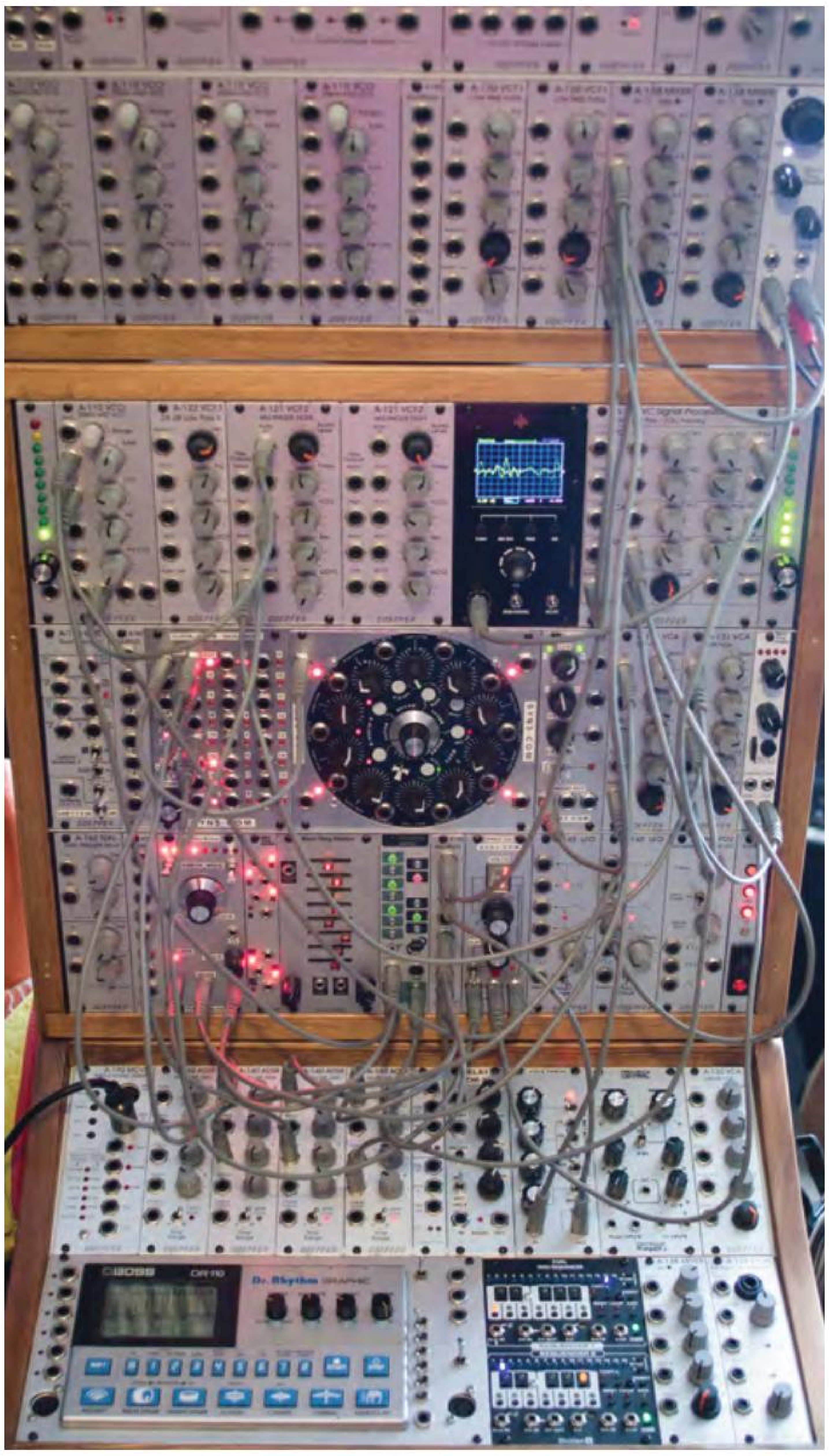


*Fig.2. Modular synthesiser built by Grant Stevens (**syn3.com**) (Photo: Harvey Rothman)*

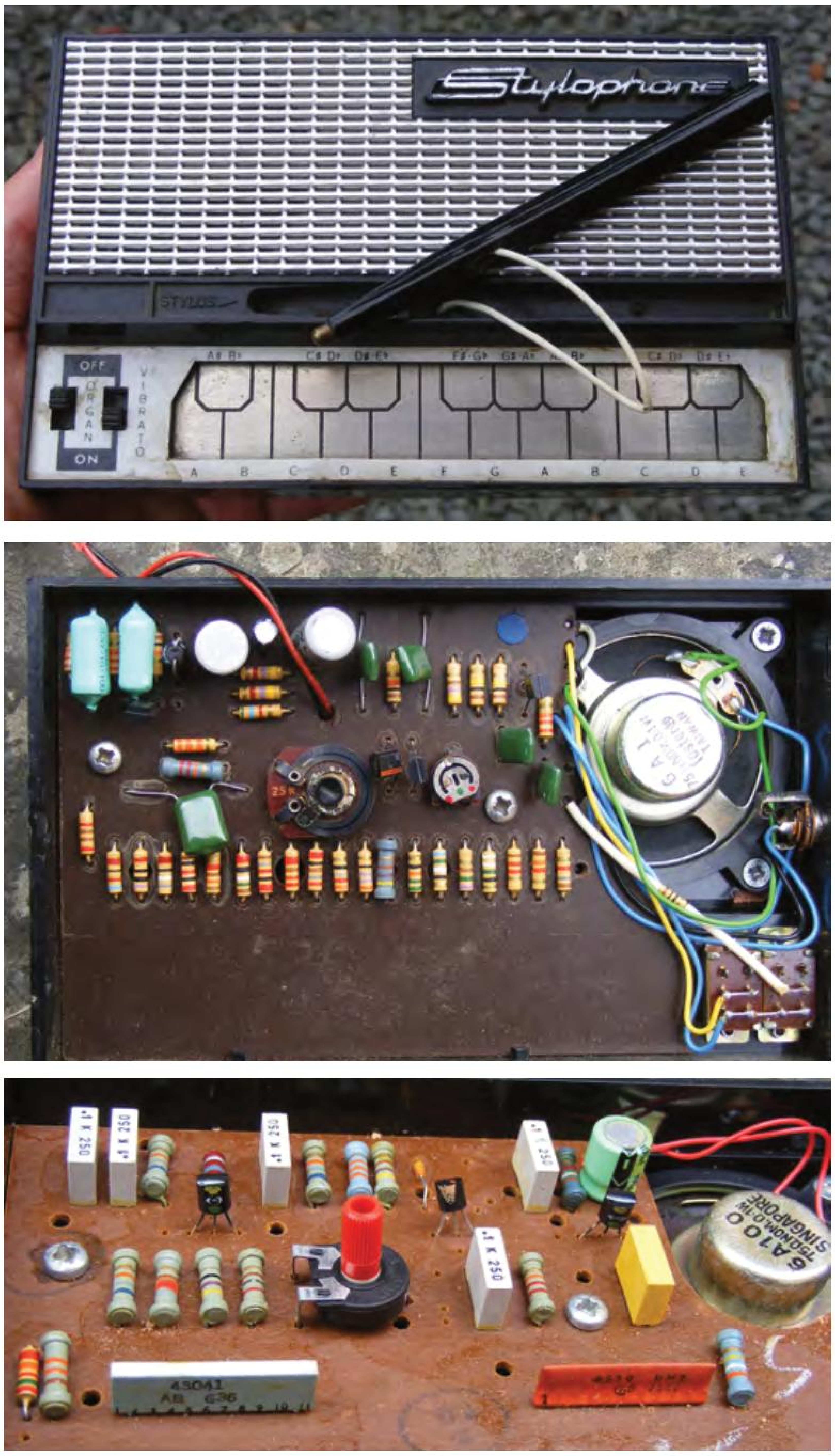


Fig.3. The original 1973 unijunction Stylophone – the consumer market's first taste of electronic sound synthesis, and still going strong today. Note the middle photo from this early version shows a string of odd-value resistors, which were later replaced by a pair of thick-film resistor networks (the large blocks at the bottom of the lower photo).

Fig.4. The latest Stylophone incarnation, the Dubreq Gen X-1 – and no, not digital – it's a real analogue synthesiser.

cheerful and popular Stylophone (Fig.3). It embodied the most basic synth system: an oscillator, a stylus keyboard to play notes and modulation for vibrato. The original Stylophone used a unijunction transistor, later replaced with the ubiquitous, low-cost 555 eight-pin timer IC. It had a unique and nasty electronic sound, immortalised on David Bowie's *Space Oddity*.

The first electronic music project I built (aged 13) was the *Music Box* from *Practical Wireless* (Jan 1976), a 555-based 'Stylophone'. It was a nightmare, with a preset resistor for every note. Since then, *EPE* has published several 'Stylophones'. The *Mini Electronic Organ* from J*aycar Short Circuits Vol. 2* was very popular with my students for a while (available as a free download from the Jaycar site) and I have also designed several 'Stylophone' circuits. My latest, the Gen X-1 (Fig.4), is the world's lowest-cost real analogue synthesiser, see: **https://youtu.be/An-Q7Dn8dm4**. (Later, I'll give circuits for home constructors.)

Power supplies

I'll start with that that aspect of audio design that is all too often considered secondary, but which can really make or break an audio design – the power supply. Professional modular analogue synthesisers typically use

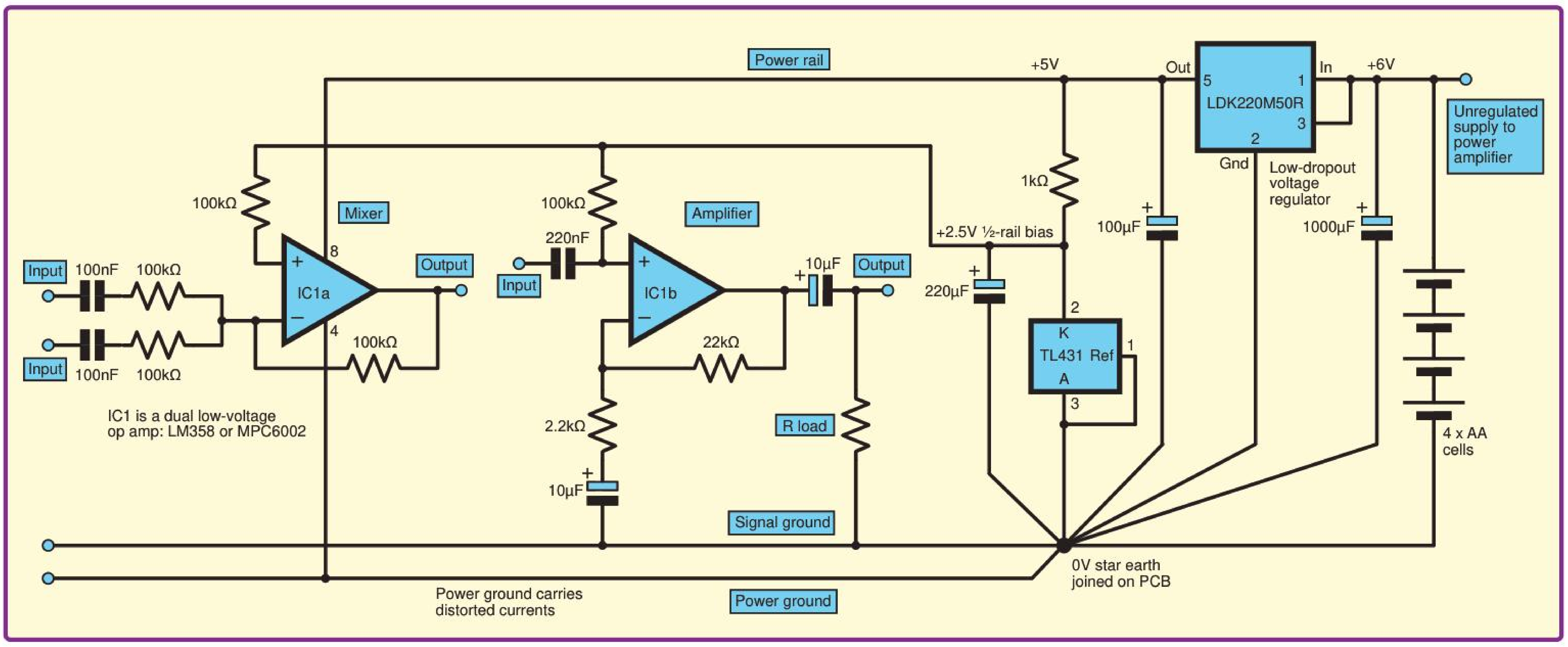

Power rail
+5V
Out
5
1
In
+6V
LDK220M50R
3
2
Gnd
Low-dropout voltage regulator
Unregulated supply to power amplifier
100kΩ
Mixer
100kΩ
Amplifier
1kΩ
100µF
1000µF
220nF
+2.5V ½-rail bias
8
Input
100nF
100kΩ
IC1a
Output
Input
IC1b
10µF
Output
220µF
2
Input
100nF
100kΩ
4
100kΩ
22kΩ
K
TL431 Ref
A
1
3
IC1 is a dual low-voltage op amp: LM358 or MPC6002
2.2kΩ
R load
4 x AA cells
10µF
Signal ground
0V star earth joined on PCB
Power ground carries distorted currents
Power ground

Fig.5. Stable power supplies are crucial for stable pitch. This circuit illustrates how to power single-rail op amp circuits; for example synthesisers, such as the Gen X-1.

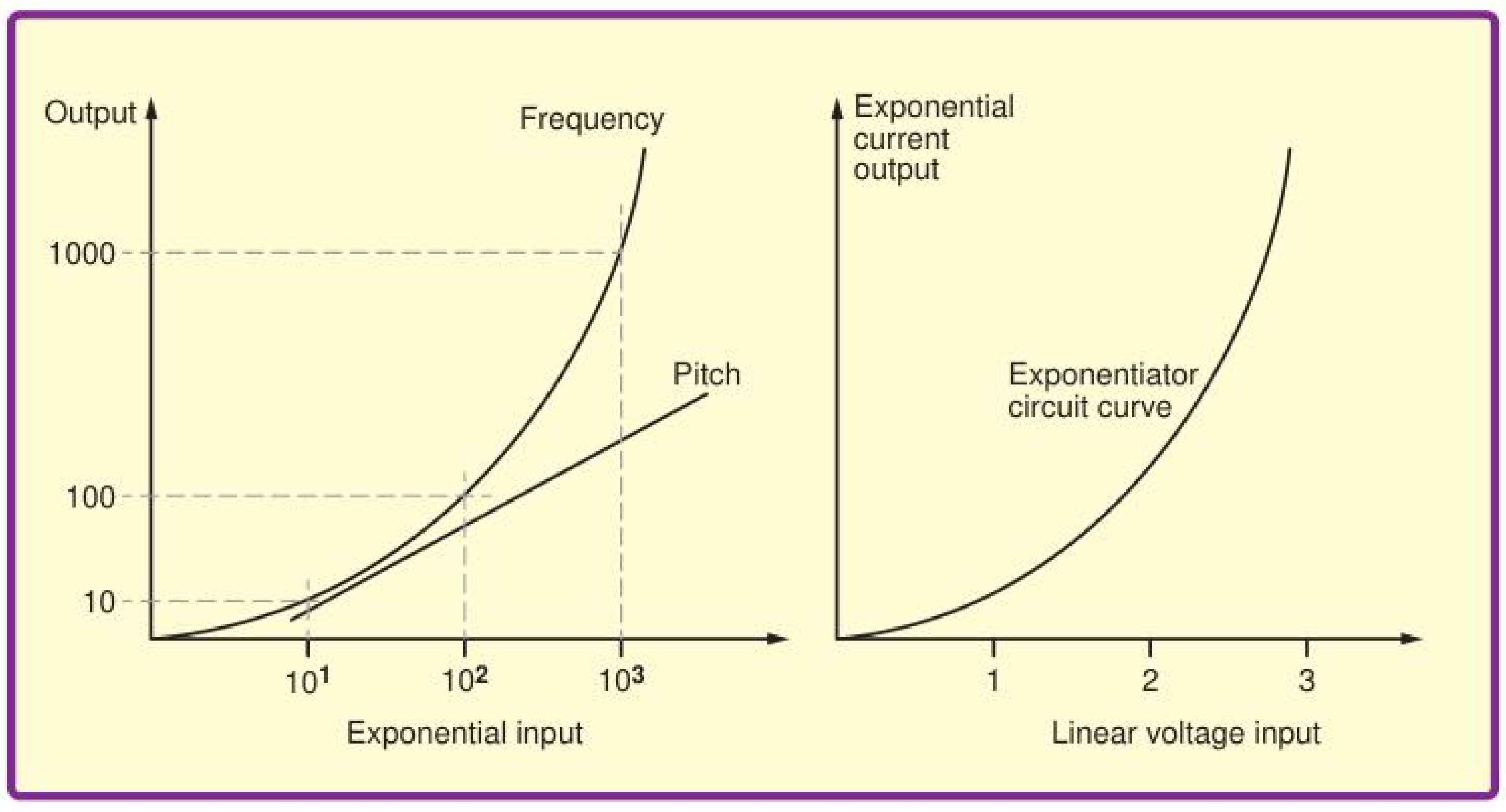


Fig.6. An exponential rise (natural multiplicative growth) in frequency is perceived as a linear rise in pitch.

±12V rails, often with an additional 5V rail for digital modules. The current consumption is generally quite high, precluding battery operation. However, the Gen X-1 and the circuits I detail here run on 5V to 9V and have low current drain. In fact, it would be possible using these circuits to make a unique battery-powered modular synth in a suitcase.

Gen-X1 power supply

It is essential that an analogue synthesiser's power supply voltage is well regulated to ensure its oscillator frequency is stable. A musician's sense of pitch is very sensitive and drifts or modulation will be easily picked up by the human ear. With battery supplies there is little spare voltage available for headroom across the regulator, so it is essential a low dropout voltage (LDO) device is used. Battery-powered supplies are normally single-rail topology, so a centre-bias or half-rail voltage generator needs to be added. A potential divider consisting of two equal-value resistors has much too high a source resistance to ensure stability, necessitating a voltage regulator for the half-rail. Fig.5 shows the power supply of the Gen-X1, which is powered by four AA batteries, regulated down to 5V. The centre rail is derived from the common TL431 2.5V shunt regulator.

Perception and pitch

Humans, as with most organisms, have a logarithmic stimuli response to accommodate wide environmental variations. Unfortunately, electronics is linear, as illustrated by Ohm's law and our old friend, the frequency formula, $f = 1/(2\pi RC)$. Human frequency perception needs an exponential rise in frequency (Fig.6) for it to be perceived as a steady increase in the sensed pitch. We recognise (hear) a doubling of pitch as an octave, which means the frequency has to double for each octave on the musical scale. So with middle C on the keyboard being 261.63Hz, an octave up would be 514Hz, the next is at 1028Hz, and so on. A linear *response* would rise by the same 'quantity of hertz' (an arithmetic progression) rather than doubling. Dealing with the exponential sense/linear electronics dichotomy accounts for the unique circuits and components that characterise not just analogue synthesisers but much of analogue audio electronics. The most common example is the use of a logarithmic attenuator as a volume control.

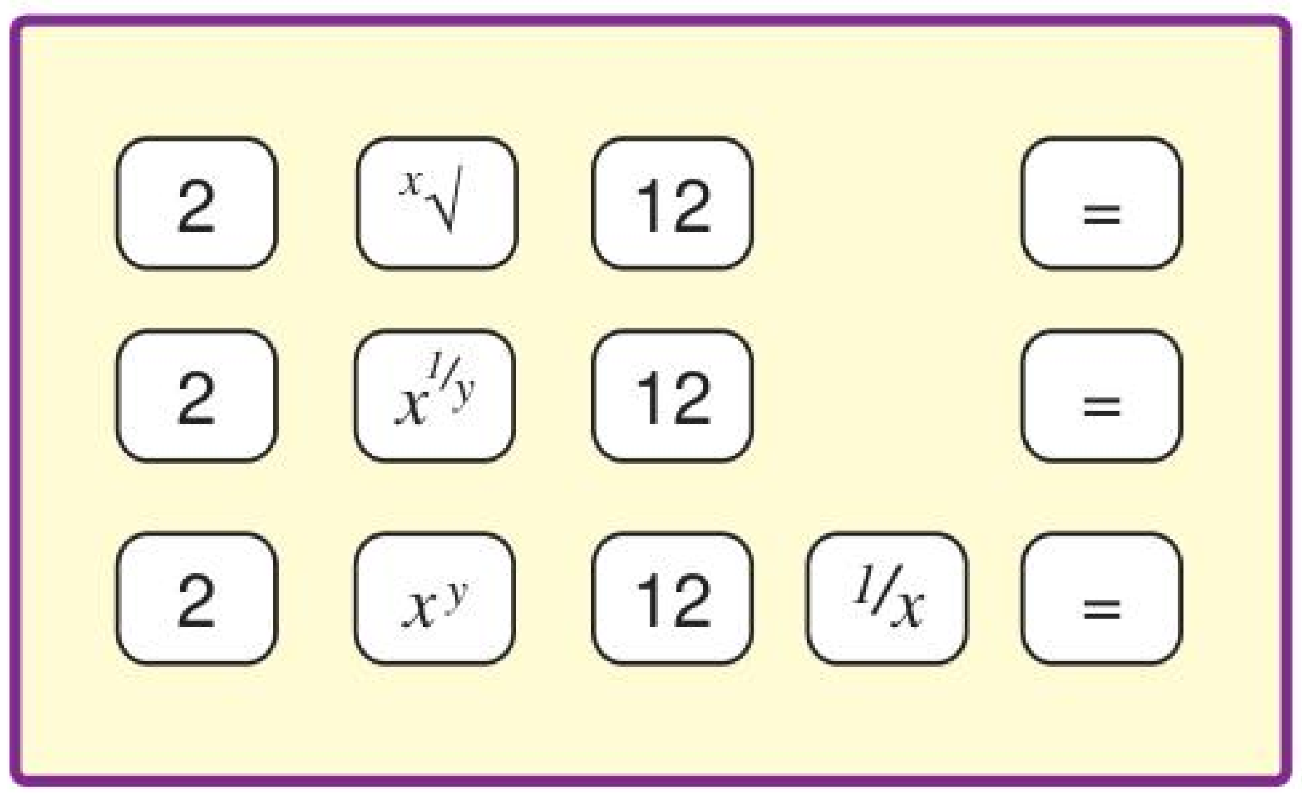
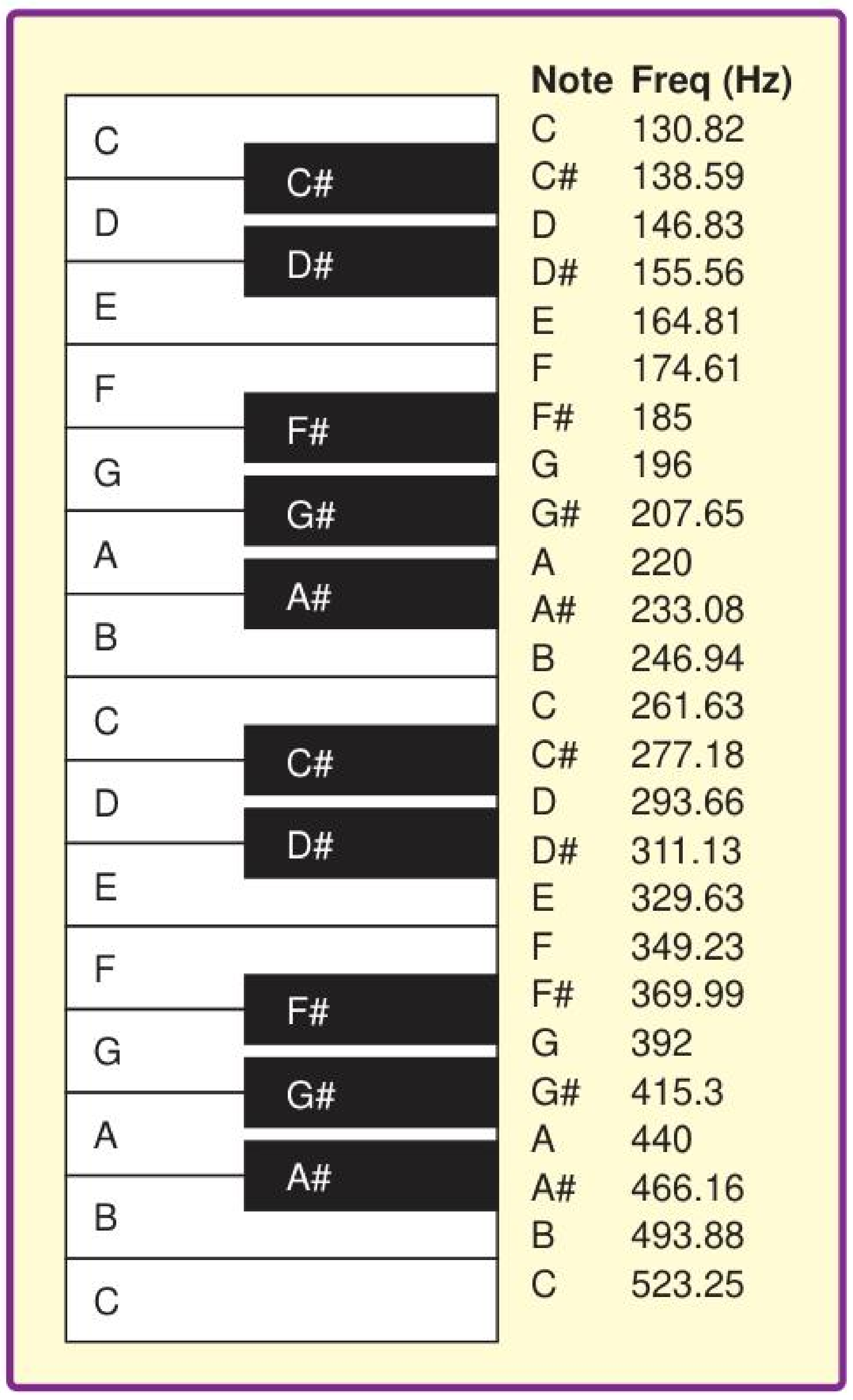

2
$\sqrt[x]{}$
12
=
2
$x^{1/y}$
12
=
2
x^y
12
$1/x$
=

Fig.7. Some generic calculator routes to roots; in this case, the twelfth of 2.

The musical scale

Most musical instruments for Western music use the 'equal-tempered scale', in which the octave is split into 12 notes called semitones. The spacing of the notes is critical because they should all represent an equal pitch increase. This means the frequency spacing between all the notes should be according to the same frequency ratio. To achieve this we have to multiply each consecutive note by a specific number. So how do we find this 'special' number?


C
C#
D
D#
E
F
F#
G
G#
A
A#
B
C
C#
D
D#
E
F
F#
G
G#
A
A#
B
C

Note	Freq (Hz)
C	130.82
C#	138.59
D	146.83
D#	155.56
E	164.81
F	174.61
F#	185
G	196
G#	207.65
A	220
A#	233.08
B	246.94
C	261.63
C#	277.18
D	293.66
D#	311.13
E	329.63
F	349.23
F#	369.99
G	392
G#	415.3
A	440
A#	466.16
B	493.88
C	523.25

Fig.8. Relation of notes on a musical keyboard to frequency.

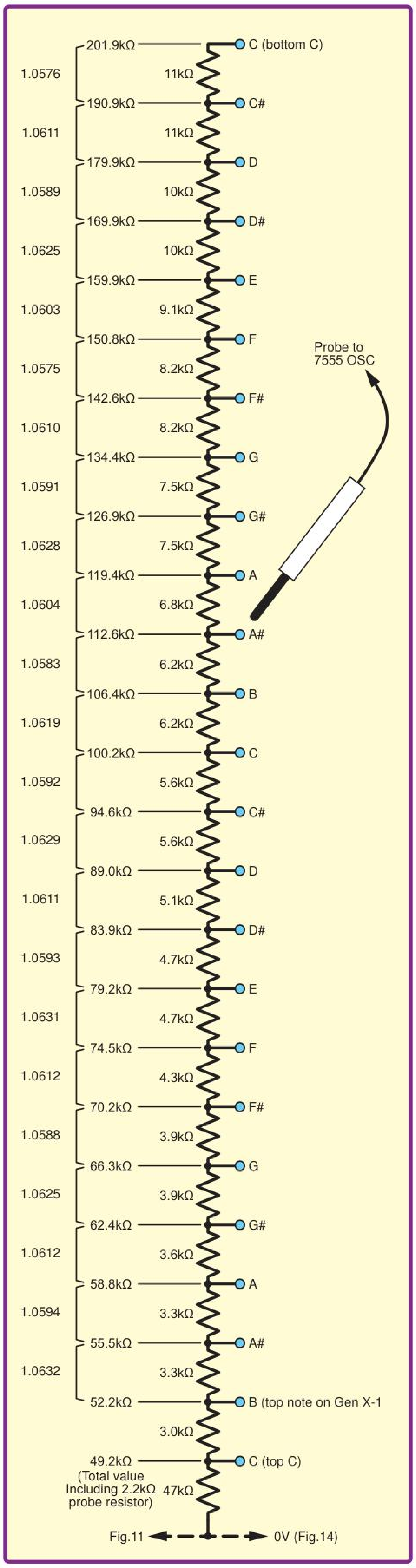

201.9kΩ
C (bottom C)
1.0576
11kΩ
190.9kΩ
C#
1.0611
11kΩ
179.9kΩ
D
1.0589
10kΩ
169.9kΩ
D#
1.0625
10kΩ
159.9kΩ
E
1.0603
9.1kΩ
150.8kΩ
F
Probe to 7555 OSC
1.0575
8.2kΩ
142.6kΩ
F#
1.0610
8.2kΩ
134.4kΩ
G
1.0591
7.5kΩ
126.9kΩ
G#
1.0628
7.5kΩ
119.4kΩ
A
1.0604
6.8kΩ
112.6kΩ
A#
1.0583
6.2kΩ
106.4kΩ
B
1.0619
6.2kΩ
100.2kΩ
C
1.0592
5.6kΩ
94.6kΩ
C#
1.0629
5.6kΩ
89.0kΩ
D
1.0611
5.1kΩ
83.9kΩ
D#
1.0593
4.7kΩ
79.2kΩ
E
1.0631
4.7kΩ
74.5kΩ
F
1.0612
4.3kΩ
70.2kΩ
F#
1.0588
3.9kΩ
66.3kΩ
G
1.0625
3.9kΩ
62.4kΩ
G#
1.0612
3.6kΩ
58.8kΩ
A
1.0594
3.3kΩ
55.5kΩ
A#
1.0632
3.3kΩ
52.2kΩ
B (top note on Gen X-1
3.0kΩ
49.2kΩ (Total value Including 2.2kΩ probe resistor)
47kΩ
C (top C)
Fig.11
0V (Fig.14)

Fig.9. For linear oscillators, an exponential resistor chain with the ratio of 1.0595 gives the correct musical scale. Note that this resistor network can be used in two different ways. 1) The bottom terminal is grounded (Fig.14) and 2) taken to the oscillator capacitor/IC1 pin 2 (Fig.11).

It can be calculated by finding that number, which when multiplied by itself 12 times gives 2. In other words, the 12th root of 2 or $\sqrt[12]{2} = 2^{1/12}$. Roots

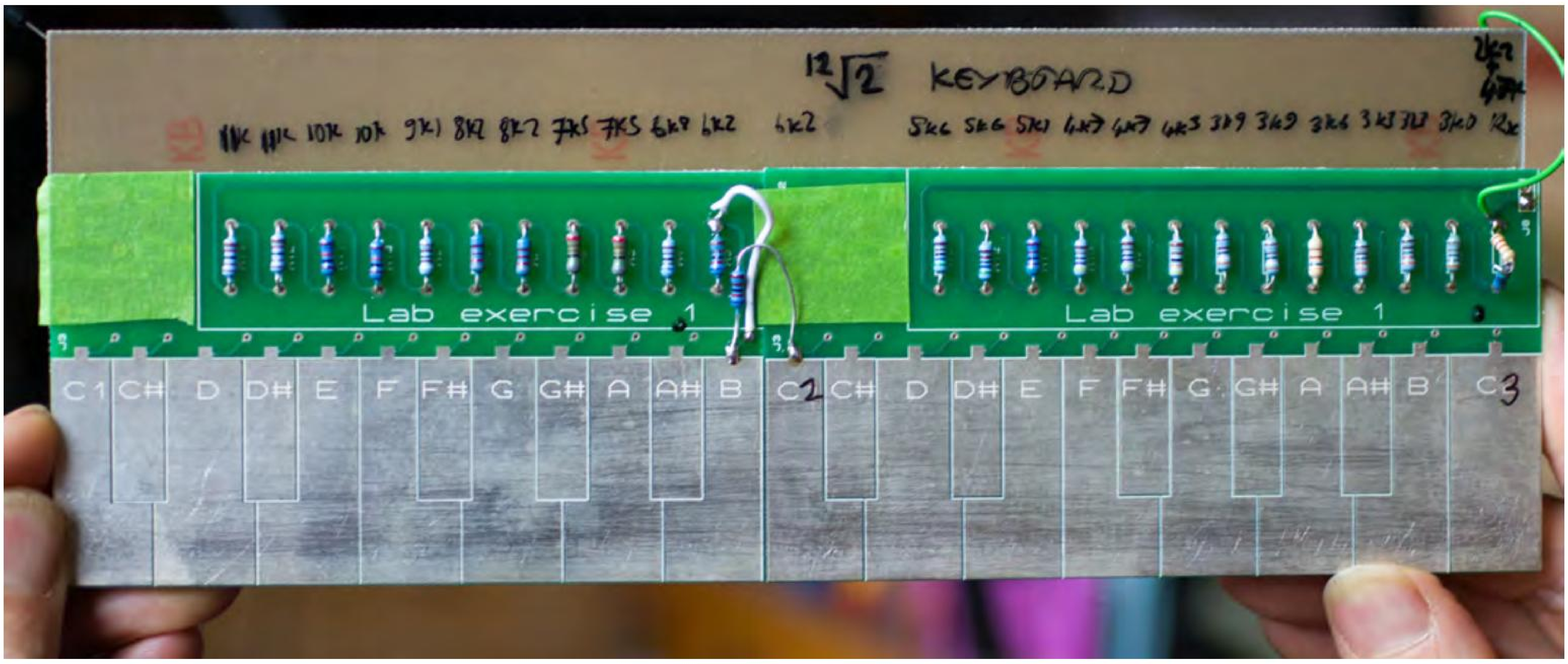

12√2 KEYBOARD
Lab exercise 1
Lab exercise 1
C1 C# D D# E F F# G G# A A# B C2 C# D D# E F F# G G# A A# B C3

Fig.10. 12th root of 2 keyboard using a wide range of resistor values. (Photo: Harvey Rothman)

can be worked out on a scientific calculator with the key sequences shown in Fig.7.

The answer you should get is $2^{1/12}$ = 1.0595 (approximately), which enables the frequency of each note to be worked out. (You can test it by calculating 1.0595^{12} – you should get 2, or *very* close). So, if we start with A = 440Hz and multiply by it by $2^{1/12}$ (1.0595) we will get the next note, A# = 466.16Hz. To get B, the next note up, we multiply again by 1.0595, which takes us to 493.88Hz … and so on to produce the table shown in Fig.8.

Note that the only integer (whole number) frequencies are the A notes. By convention, in an orchestra this is set by the oboe at A = 440Hz. The oboe is used because as a wind instruments it is more stable than ones using strings, which of course have to be tuned at the start of each performance.

Why do we have to do all this maths? It's so we can work out the resistor values to control an oscillator to give us accurate notes. I never again want to twiddle 24 presets to tune a two-octave keyboard; much better to have a string of resistors with values spaced by a ratio of 1.0595. We can then use this exponential keyboard to control a conventional linear oscillator such as the classic 555 timer chip. (Later versions of the original Stylophone used precision thick-film resistor networks).

The resulting resistor ladder is shown in Fig.9, along with the actual ratios obtained using standard E24 resistors, and Fig.10 shows the keyboard. You can see there are a few deviations using the limited E24 range, the worst being 1.0629 and 1.0575. Using a resistor chain means the keyboard defaults to the highest note if the stylus lands such that it shorts two adjacent 'keys' on the keyboard.

In some designs, the resistors are all connected in parallel to a single node – not series. In this case if two adjacent notes are shorted by the probe then a high-pitched squeak occurs. Surprisingly, I found that on the Gen X-1 this effect sounded unique and became part of the design's 'sound'.

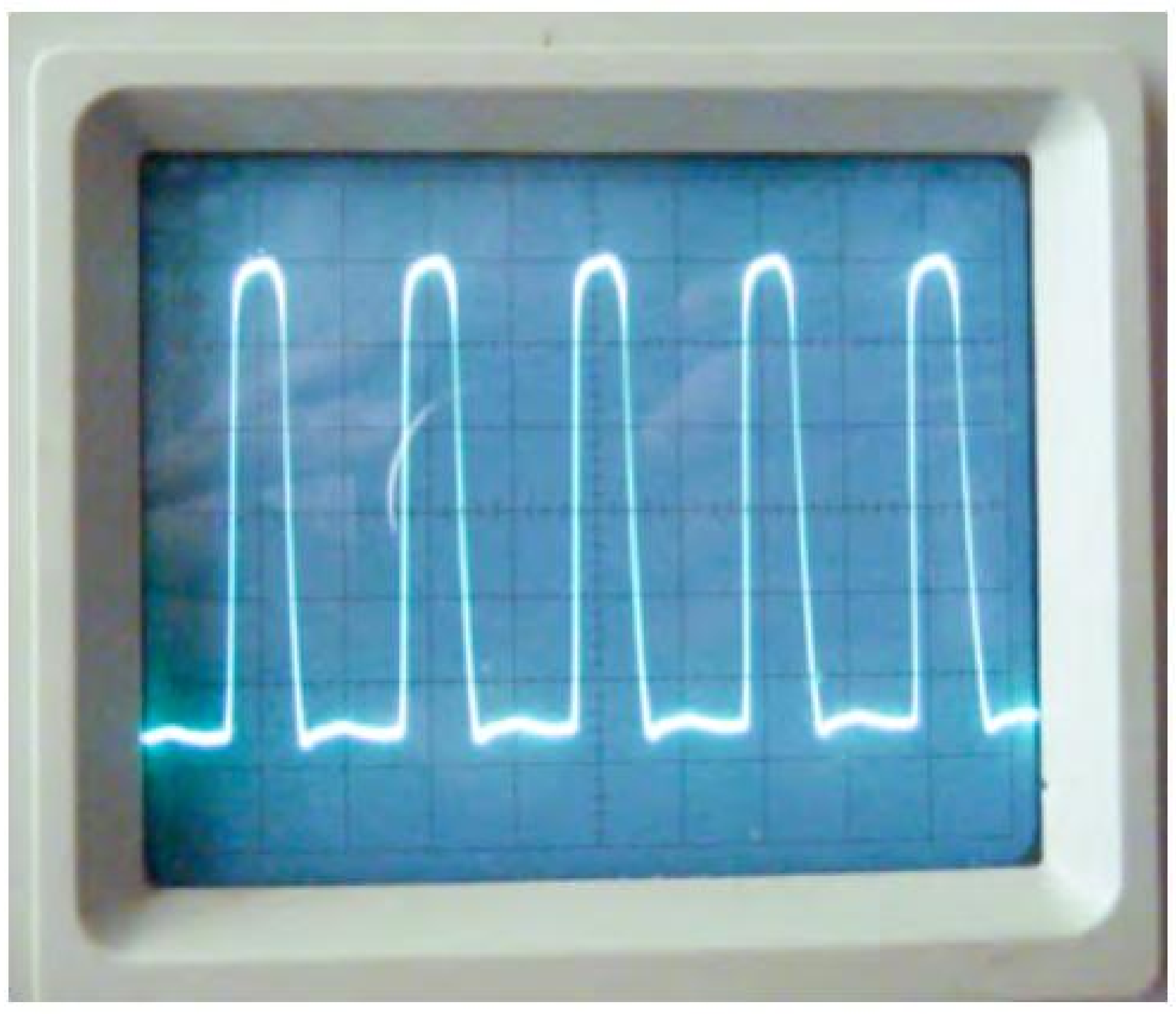


Fig.12. The output waveform of the low-power 'Stylophone' with the top cut switched in.

Ultra-low-power 'Stylophone'

My latest simple 'Stylophone' circuit is shown in Fig.11. This minimalist instrument uses a 7555 IC, the updated CMOS low-power version of the original 555. It is surprisingly stable and unaffected by temperature – I can

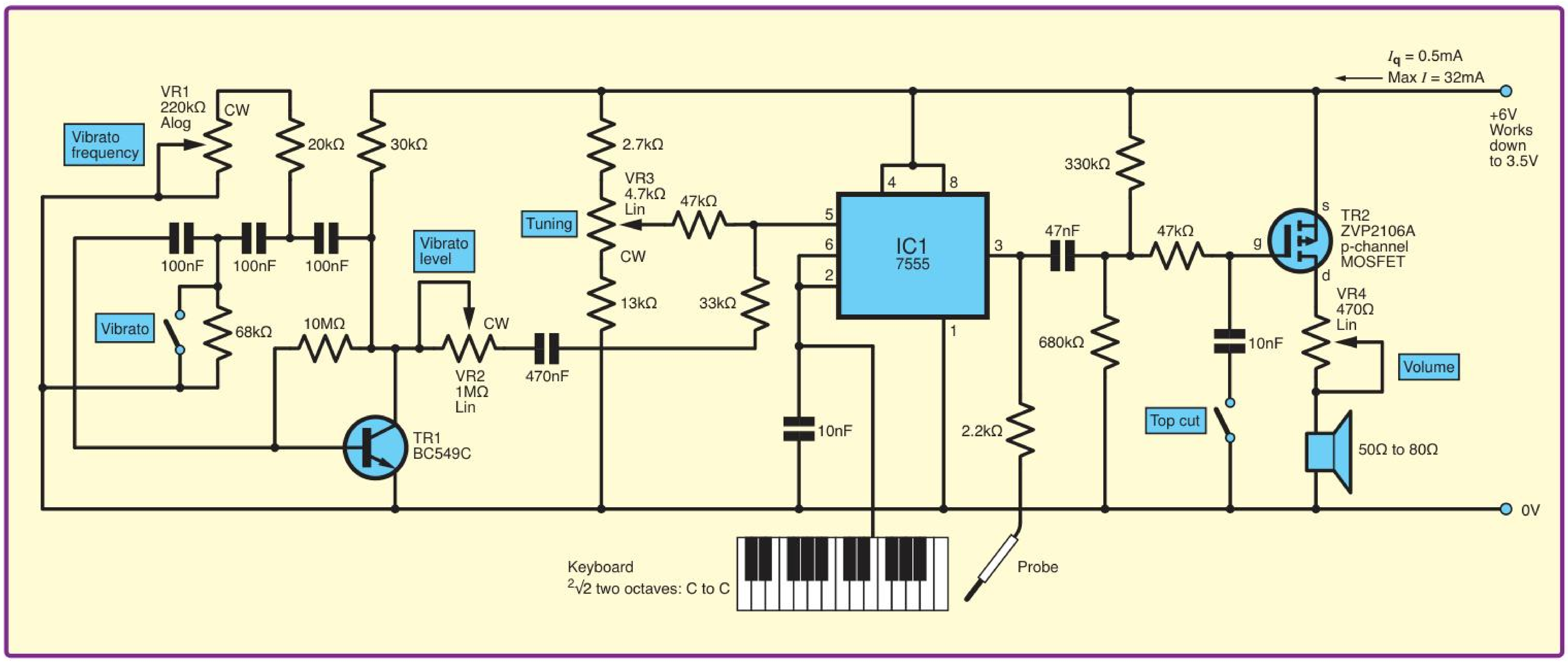

VR1
220kΩ
Alog
CW
Vibrato frequency
20kΩ
30kΩ
100nF
100nF
100nF
Vibrato
68kΩ
10MΩ
Vibrato level
VR2
1MΩ
Lin
CW
470nF
TR1
BC549C
Tuning
2.7kΩ
VR3
4.7kΩ
Lin
CW
13kΩ
47kΩ
33kΩ
10nF
Keyboard
²√2 two octaves: C to C
IC1
7555
4
8
5
6
2
3
1
2.2kΩ
Probe
47nF
330kΩ
680kΩ
47kΩ
10nF
Top cut
g
s
d
TR2
ZVP2106A
p-channel
MOSFET
VR4
470Ω
Lin
Volume
50Ω to 80Ω
Iq = 0.5mA
Max I = 32mA
+6V
Works
down
to 3.5V
0V

Fig.11. A low-power consumption 'Stylophone' circuit. It uses only 0.5mA when no note is playing; 35mA when a note is generated.

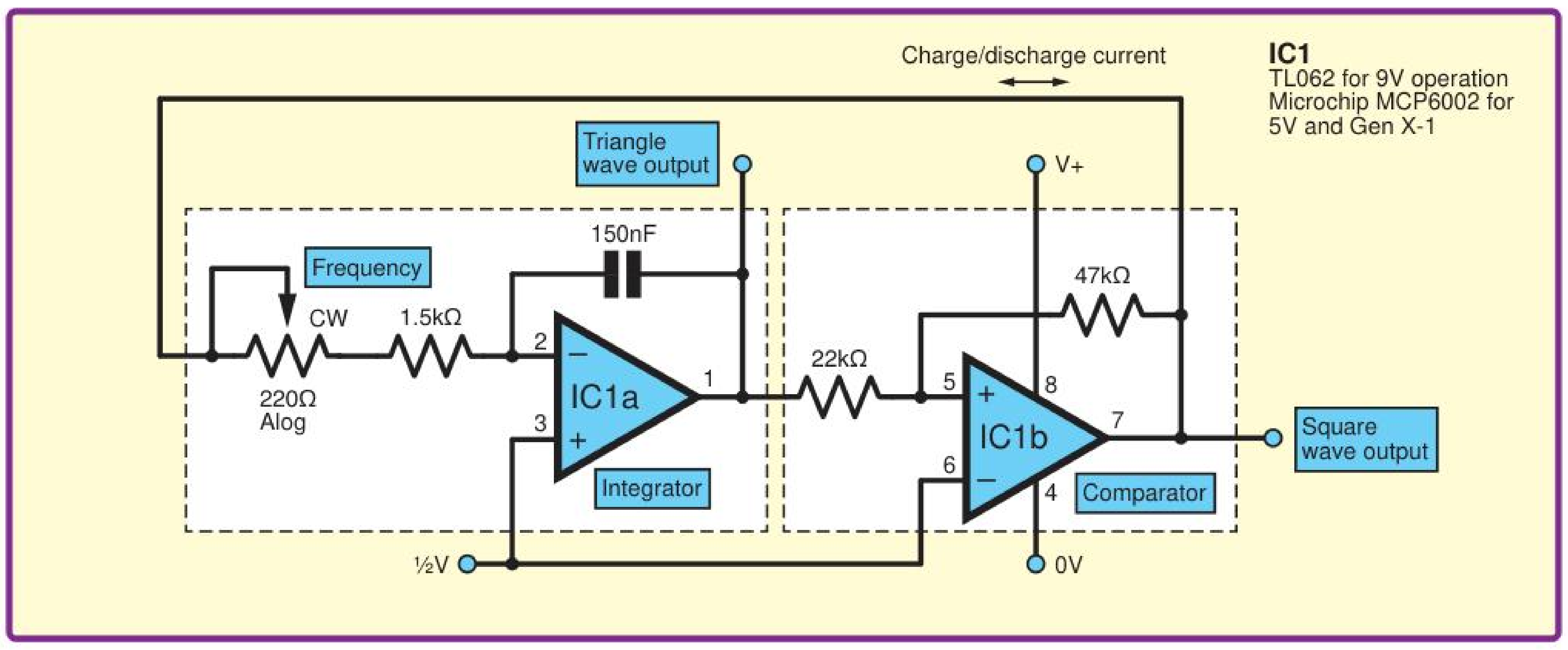

Charge/discharge current
IC1
TL062 for 9V operation
Microchip MCP6002 for 5V and Gen X-1
Triangle wave output
V+
150nF
Frequency
47kΩ
CW
1.5kΩ
2
22kΩ
5
8
1
IC1a
220Ω Alog
3
IC1b
7
Square wave output
6
Integrator
4
Comparator
½V
0V

Fig.13. A typical integrator/comparator low-frequency oscillator, as used in the Gen X-1.

almost touch the oscillator chip with a soldering iron to demonstrate how stable it is.

One problem with 555-based oscillators is that they normally produce square wave outputs, which sound nasty, typically harsh and 'electronic', a bit like an electronic alarm. This is because square waves have only odd harmonics (third, fifth, seventh…). It can be made to sound more 'acoustic' by making the mark-to-space ratio unequal, thereby adding some even-order harmonics, such as the second harmonic. All asymmetrical waveforms have even harmonics, which tend to sound warmer. Another advantage of using an unequal mark-to-space ratio is that the wave can be off more than it is on, as shown in Fig.12, thereby reducing power consumption. In simple designs such as this, the current is simply pulsed through the speaker using a single transistor (TR2) making a linear power amplifier such as an LM386 unnecessary. The speaker used is the 'filter' and acoustically coloured lightweight paper speakers give the best results. We went through 20 samples for the Gen X-1 design and noted that Mylar speakers sound horrible!

Modulation

A major part of analogue synthesis is modulation. In this circuit we have the most popular musical modulation effect vibrato, which is simply *frequency* modulation.

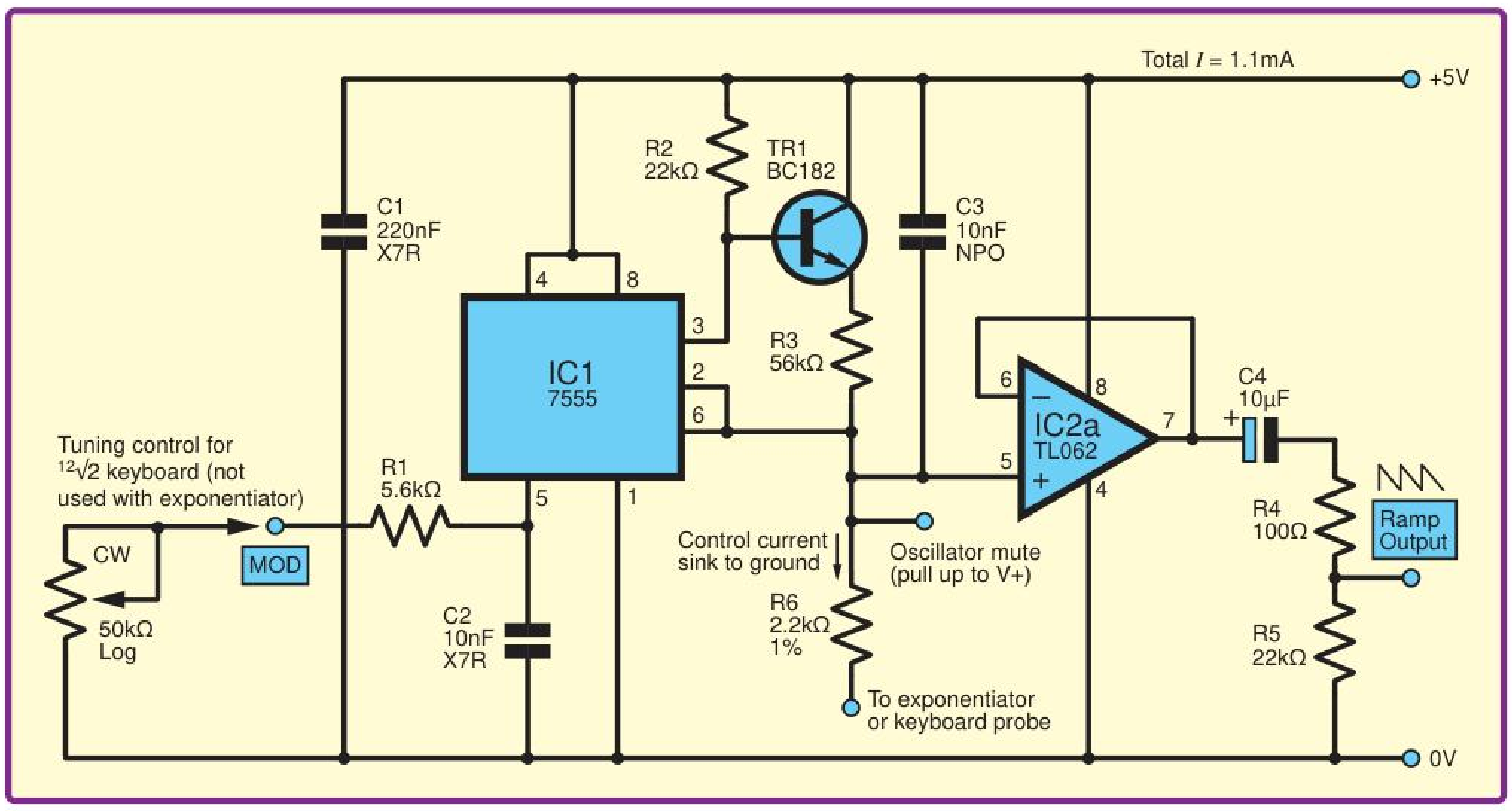

Total I = 1.1mA
+5V
R2
22kΩ
TR1
BC182
C1
220nF
X7R
C3
10nF
NPO
4
8
3
R3
56kΩ
IC1
7555
2
6
8
IC2a
TL062
7
C4
10µF
+
5
4
Tuning control for 12√2 keyboard (not used with exponentiator)
R1
5.6kΩ
5
1
R4
100Ω
Ramp Output
CW
MOD
Control current sink to ground
Oscillator mute (pull up to V+)
50kΩ
Log
C2
10nF
X7R
R6
2.2kΩ
1%
R5
22kΩ
To exponentiator or keyboard probe
0V

Fig.14. The 7555 ramp wave oscillator from a Tim Orr circuit in ETI Magazine *(Nov 1981, page 54). It can be used with the exponential keyboard or the exponentiator.*

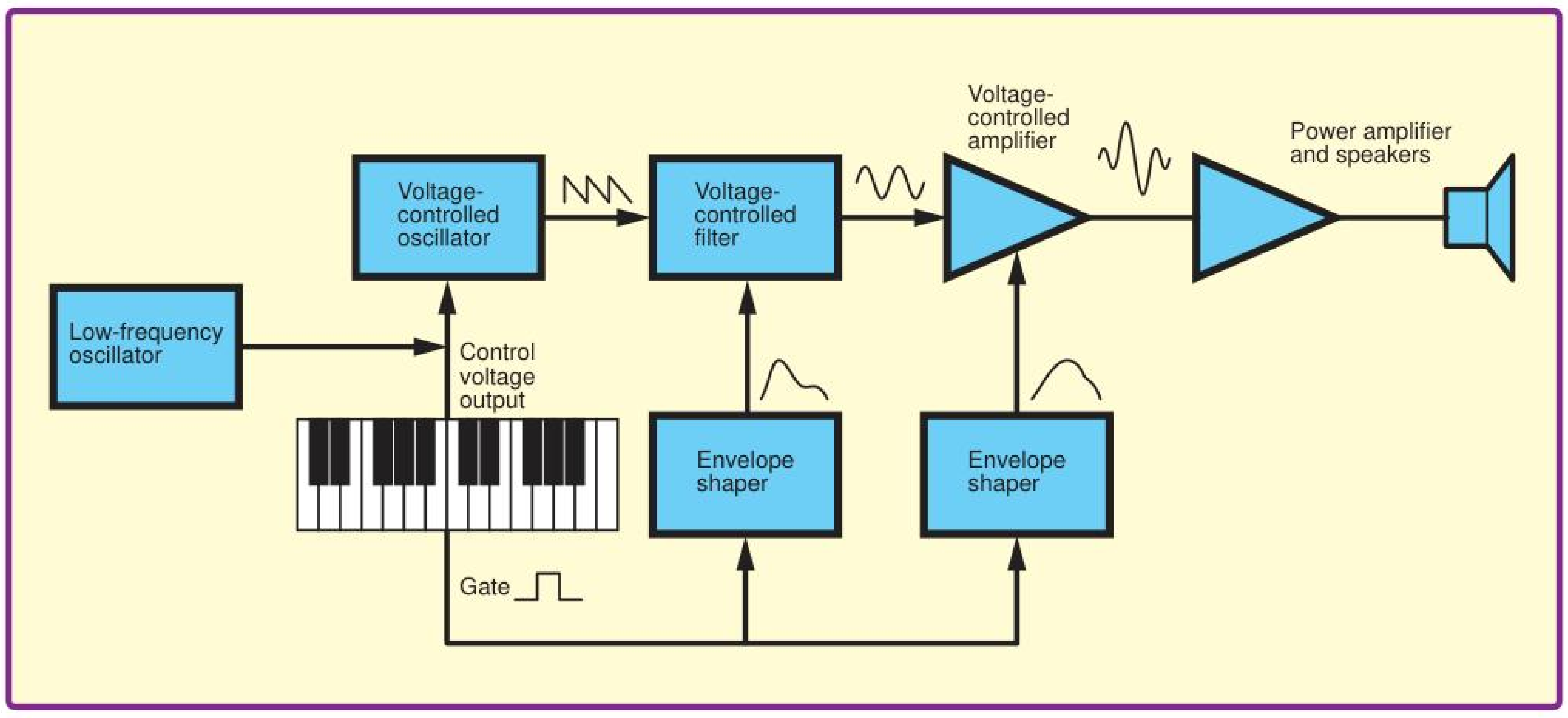

Voltage-controlled oscillator
Voltage-controlled filter
Voltage-controlled amplifier
Power amplifier and speakers
Low-frequency oscillator
Control voltage output
Envelope shaper
Envelope shaper
Gate

Fig.15. A simple synthesiser block diagram or 'patch'.

Low-frequency oscillator (LFO)

This 'Stylophone' uses the simplest LFO possible, a single-transistor phase-shift design, which is adequate for the limited range of frequencies required for vibrato, typically 2-10Hz. For true synthesis a much wider range, say 0.1 to 70Hz, is needed, which can easily be achieved by the circuit shown in Fig.13, and which was used in the Gen X-1. Interestingly most of the modulation that occurs with the 555 circuit is pulse-width modulation because the modulation pin also induces a DC shift. This is a technical defect that sounds good, a common piece of serendipity with electronic music devices.

Ramp wave

The 555 can be used to make a ramp or sawtooth wave, which is the usual basis for analogue synthesis. I used an adaptation of a circuit designed by my lecturer and mentor Tim Orr, as shown in Fig.14. A ramp wave has a smoothly descending series of even and odd harmonics that makes it especially amenable to filtering. With a resonant filter, these harmonics can be picked out as the filter frequency changes, giving the classic analogue filter 'wah' sound everybody knows and which 'most' love. This oscillator works well with the $^{12}\sqrt{2}$ equal-tempered scale keyboard described earlier. It is a bit 'clicky' though, because it is turned on and off (gated) via the stylus. Since it is a ramp rather than the switched waveform, a proper amplifier should be used.

Subtractive synthesis

The technique of removing harmonics from a harmonically rich waveform with a filter and altering the volume of an oscillator with a voltage-controlled amplifier each time a note is played is called 'subtractive synthesis'. It is the basis of most analogue synthesis, and a block diagram of a simple synth is shown in Fig.15.

Voltage control

Having made a simple instrument using a linear oscillator with an exponential keyboard I'll now introduce a new oscillator using the industry standard pioneered by Moog, called 'voltage control'. Such control has often been used in industrial electronics, but in analogue synthesisers, linear voltage changes are used to give exponential changes in frequency and amplitude, resulting in a system that sounds musical. The standard is set at 1V per octave, so that all analogue modules and keyboards are compatible with each other. This means we

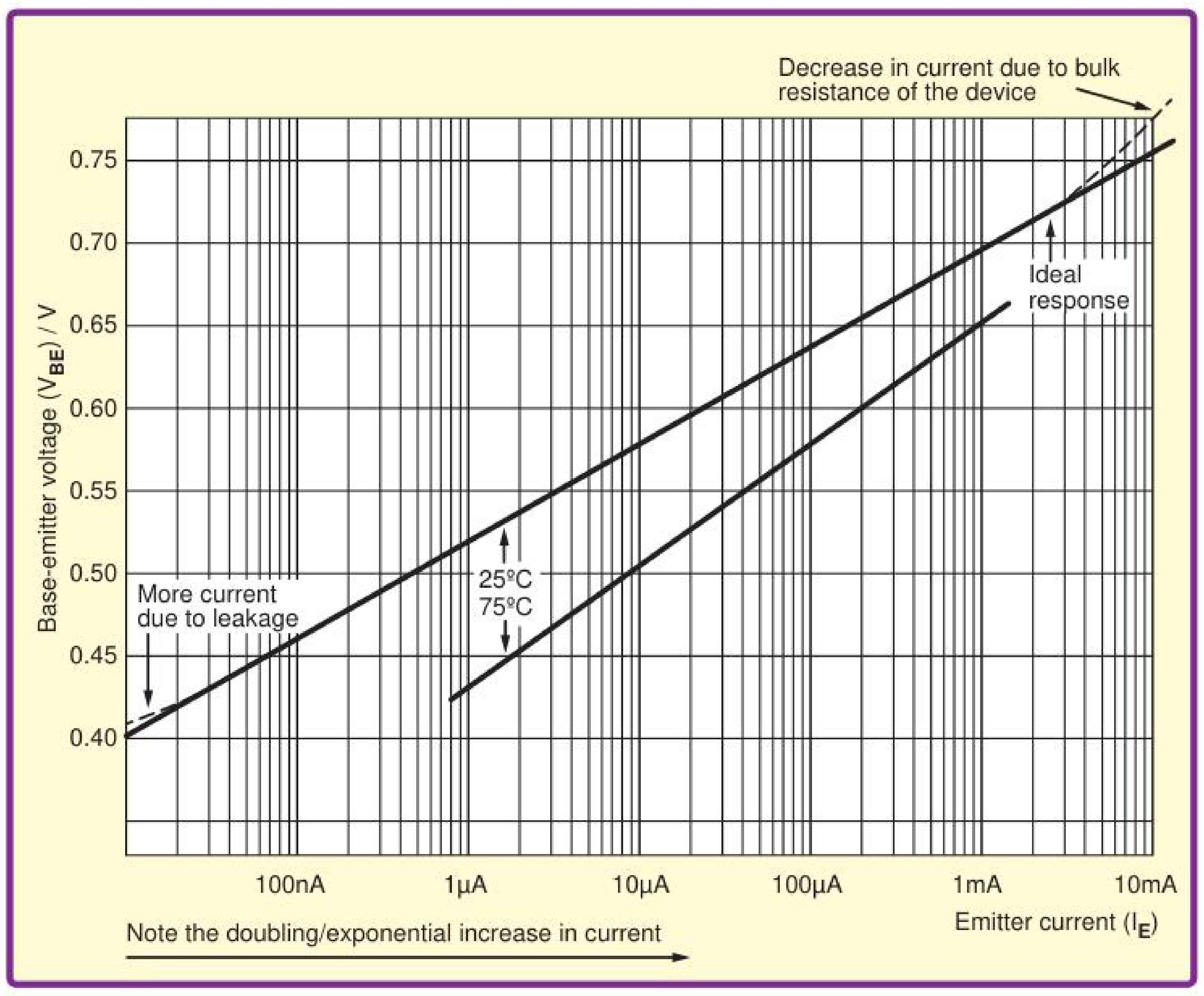


Fig.16. Graph showing relationship of transistor current with base-emitter voltage (V_{be}) and showing temperature dependencies (from Tim Orr)

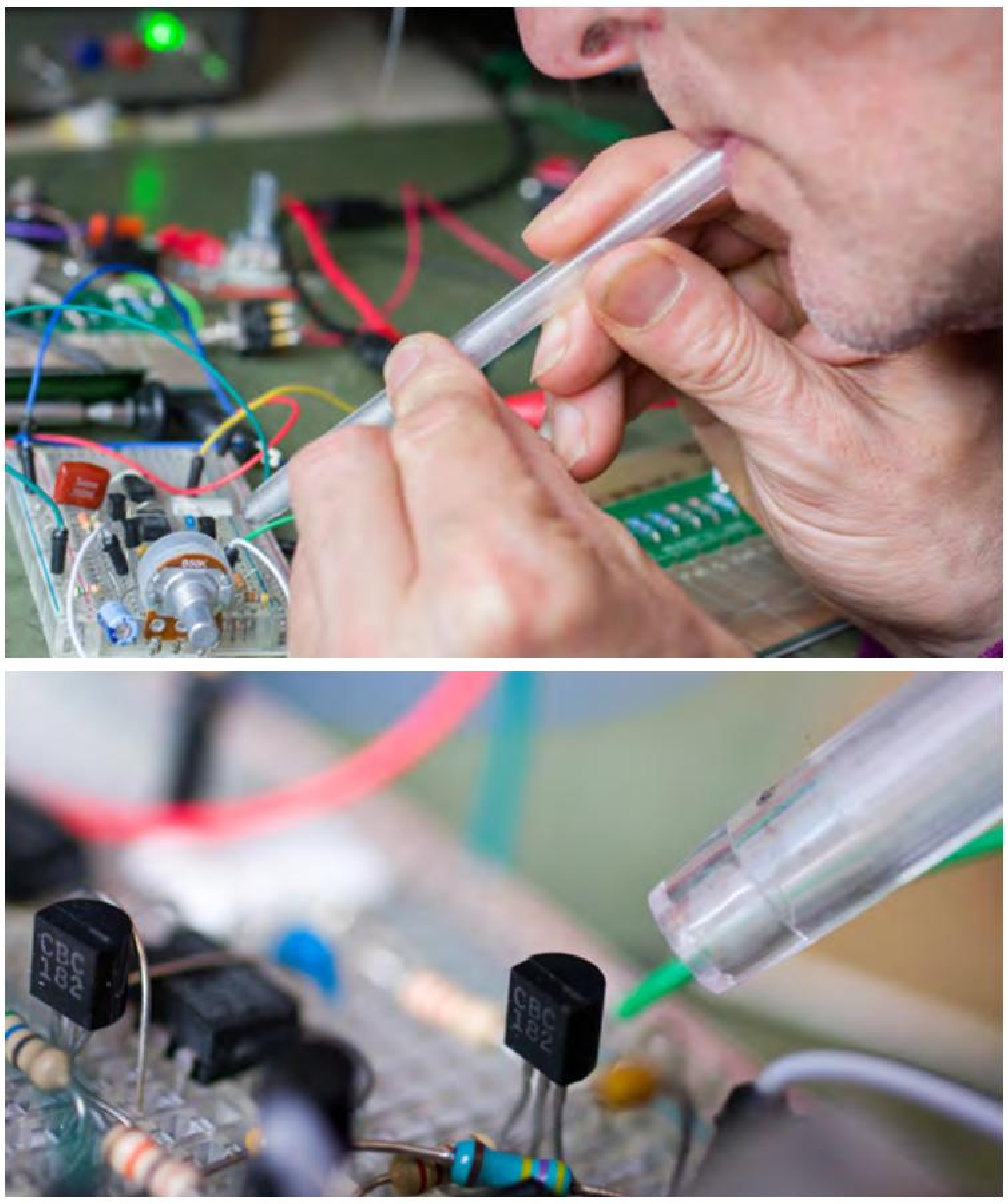
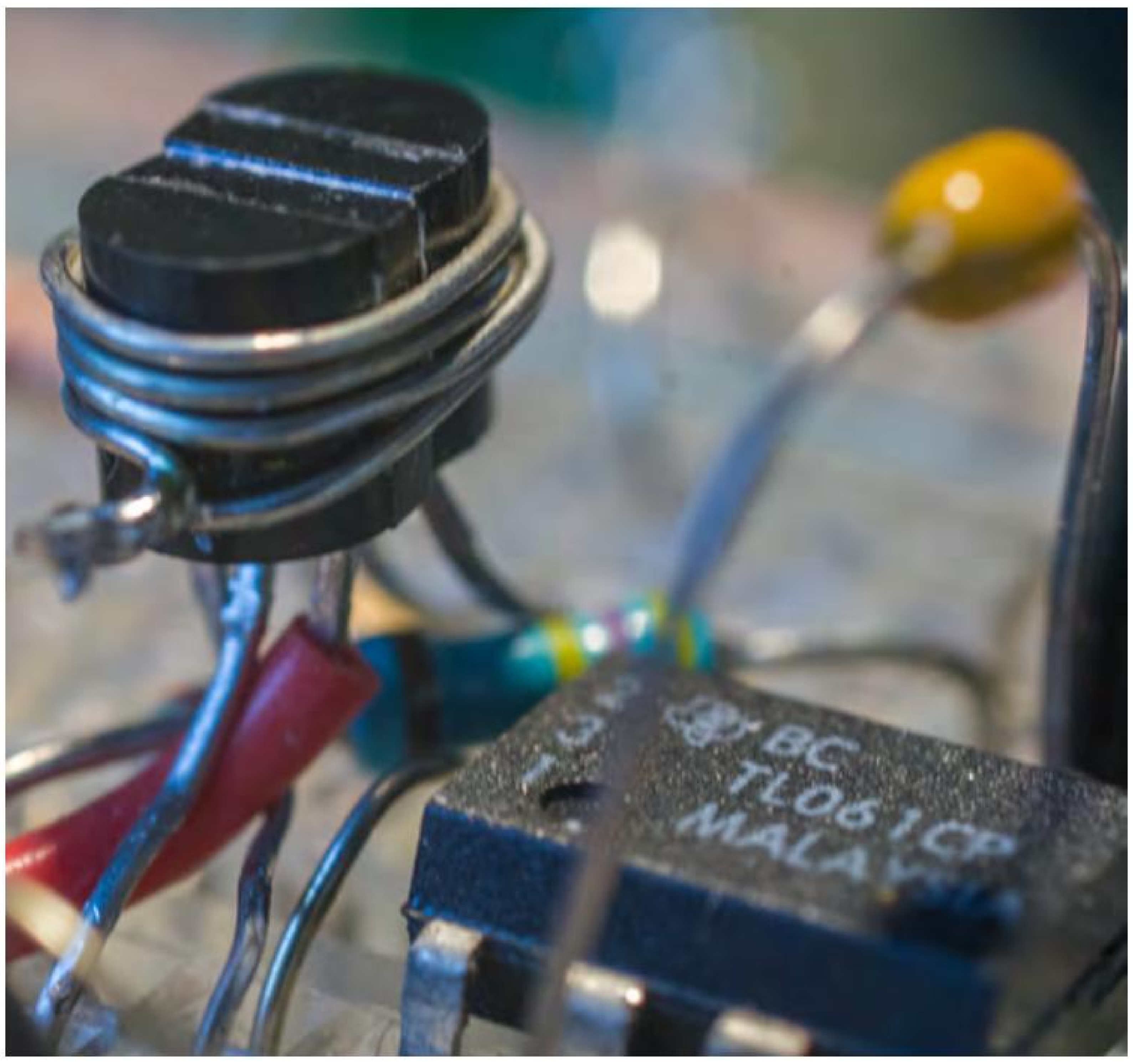


Fig.17. Gentle blowing through a Biro tube can reveal temperature sensitive components. Watch out for 'moisture' dripping onto the board! (Photos: Harvey Rothman)



Fi.18. Thermal linking of a matched V_{be} pair of transistors with tinned copper wire and a smear of heatsink compound. (Photo: Harvey Rothman)

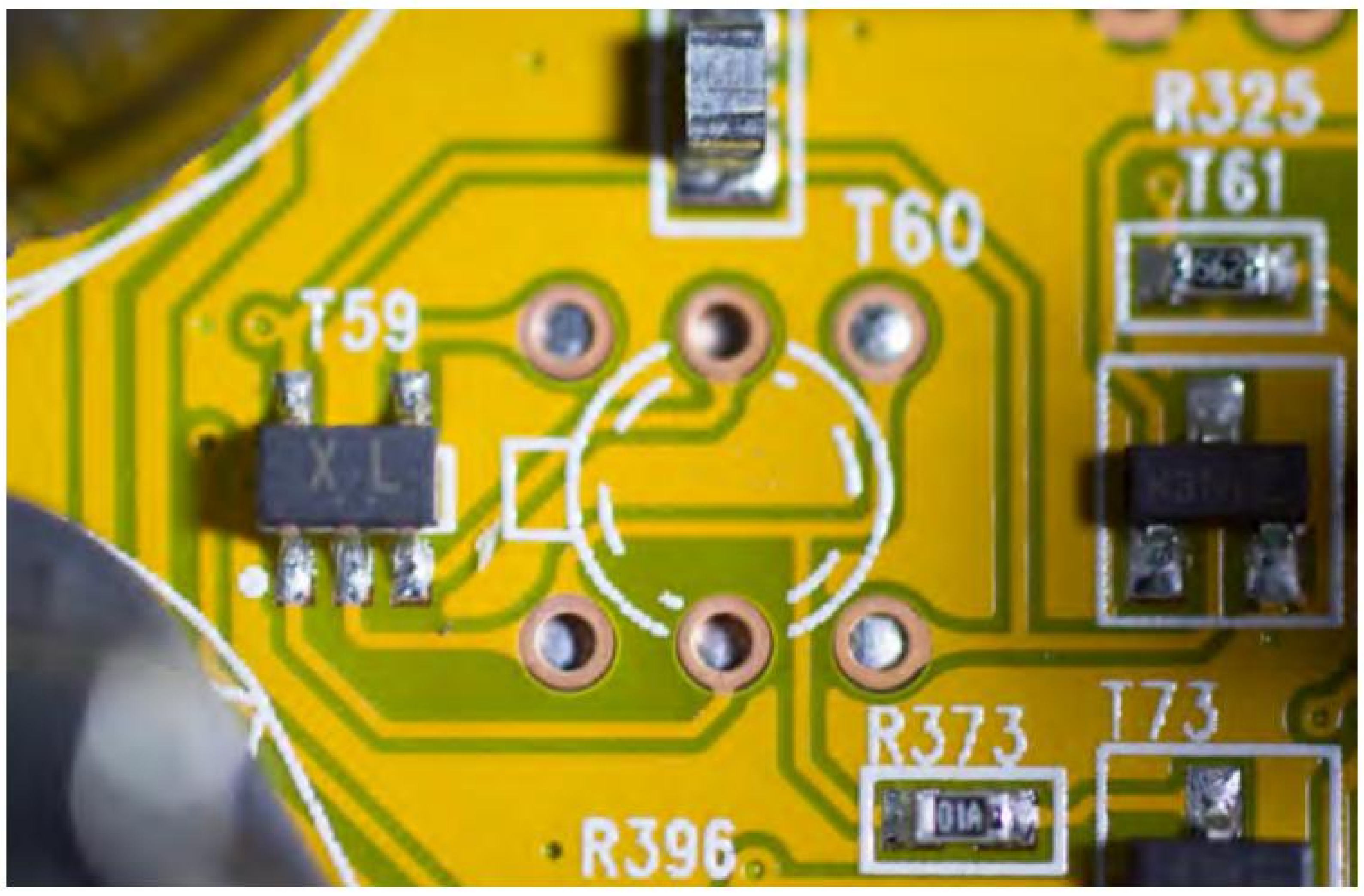


Fig.19. The SMT exponentiator dual transistor (left-centre) in the Behringer Model D.

need to introduce an extra circuit called an 'exponentiator', which converts a linear input voltage change into an exponential output change, usually a current. Another advantage of this approach is that the keyboard resistors can all be one standard value, avoiding assembly errors.

Tuning stability

The exponentiator uses the non-linear turn-on characteristic of a silicon diode or transistor junction. Most audio engineers worry about this because of the distortion produced, some even use valves to avoid it. However, for this application it is very useful, since the flow of collector current through a transistor is exponentially proportional to the base-emitter voltage, as shown in Fig.16. This property is described by the Ebers-Moll equation. Unfortunately, this relationship has two temperature-related terms in it, making these circuits prone to temperature drift, which is the main failing of analogue synthesisers. The worst drift item is the V_{be} term, which falls with temperature for a given current (–1.9mV/ºC). The circuit is so sensitive to temperature, just putting a finger on the transistor or blowing warm breath through a Biro tube will produce a very audible frequency drift upwards (as seen in Fig.17). This is because a change of just 18mV is enough to double the current, which works out at only 1.5mV per a semitone. The Gen X-1 did not have temperature compensation, I just added a trimmer for the musician to adjust.

The way round this temperature drift problem is to provide compensation with another transistor to add an equal but opposite drift for V_{be}, similar to the quiescent current compensation in class-AB amplifiers. For this to work, the cancellation transistor must be exactly identical and be thermally coupled to the exponentiating transistor. The cheap way to do this is to join a couple of matched V_{be} transistors with tinned wire and heatsink compound, as shown in Fig.18. A better way is to use monolithic dual transistors. Devices such as the metal-can LM394, used to cost around £5, but now there are cheap surface-mount devices, such as the Toshiba HN1C0FYTE85LF available from Mouser UK (see: **mouser.co.uk**). Fig.19 shows a photo of the oscillator

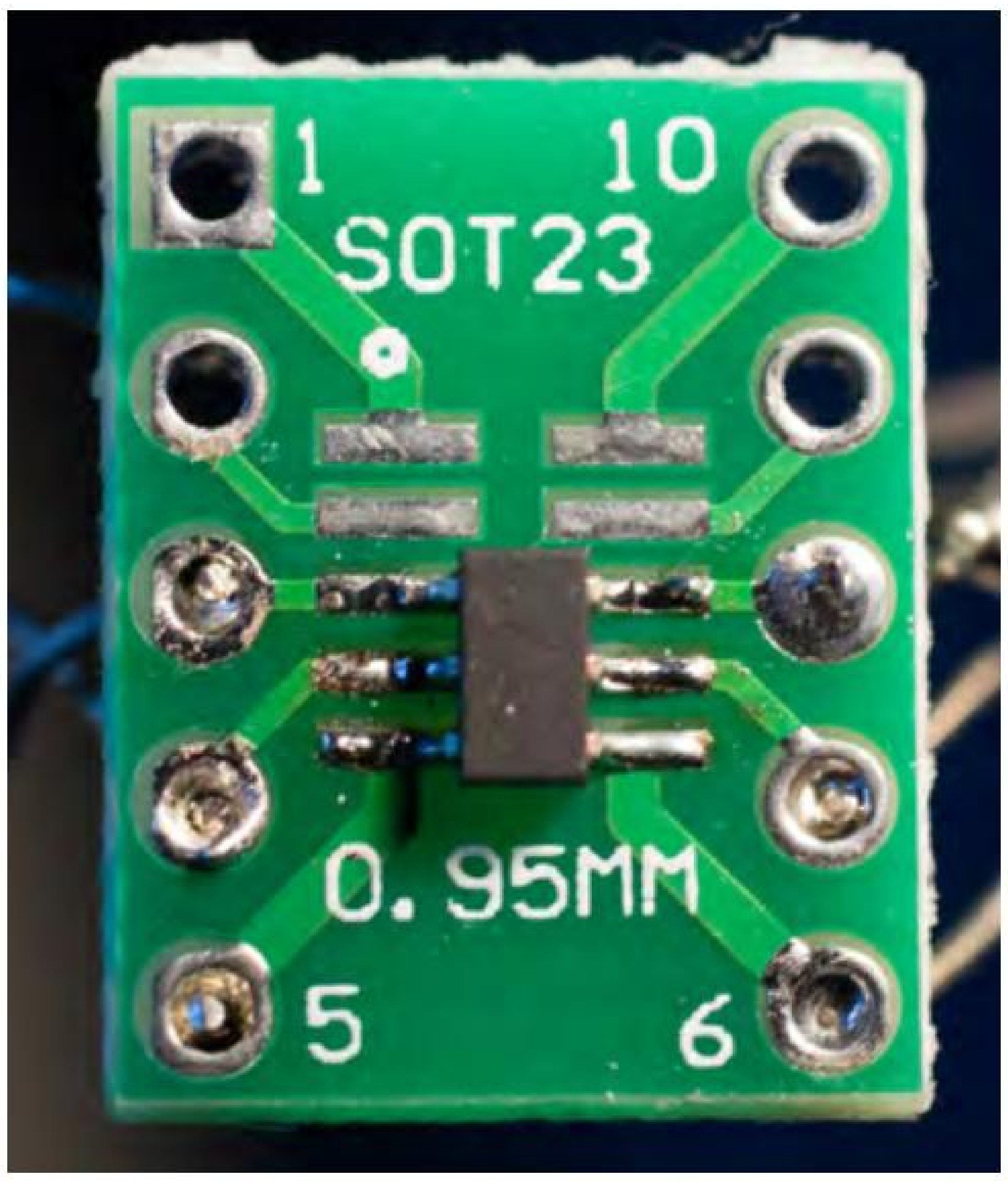

1
10
SOT23
0.95MM
5
6

Fig.20. An SMT dual transistor mounted on an expander board for breadboarding. (Photo: Harvey Rothman)

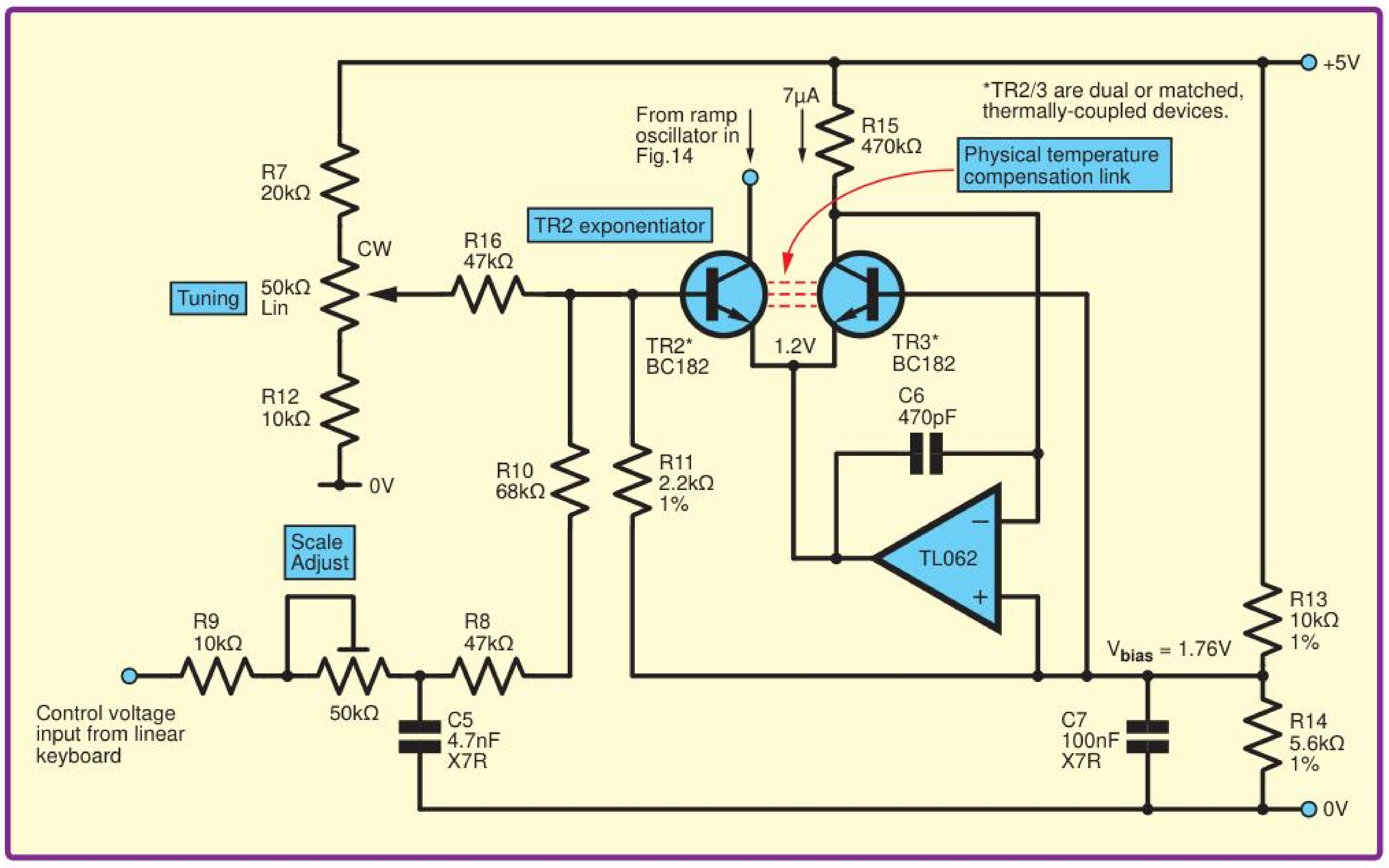

+5V
7µA
From ramp oscillator in Fig.14
R15 470kΩ
*TR2/3 are dual or matched, thermally-coupled devices.
Physical temperature compensation link
R7 20kΩ
CW
R16 47kΩ
TR2 exponentiator
Tuning
50kΩ Lin
TR2* BC182
1.2V
TR3* BC182
R12 10kΩ
C6 470pF
0V
R10 68kΩ
R11 2.2kΩ 1%
TL062
Scale Adjust
R9 10kΩ
R8 47kΩ
V_{bias} = 1.76V
R13 10kΩ 1%
Control voltage input from linear keyboard
50kΩ
C5 4.7nF X7R
C7 100nF X7R
R14 5.6kΩ 1%
0V

Fig.21. Circuit for an exponentiator suitable for the oscillator in Fig.14.

section of Behringer's Model D. The SMT dual transistor can be seen, along with the outline of the original metal-can device. When breadboarding with SMT devices it's worthwhile mounting them on SOT23 mounting boards, as shown in Fig.20.

Exponential voltage-controlled oscillator (VCO)

Fig.21 shows how a bipolar transistor (TR2) can be used as an exponential voltage-controlled current sink with the 555-ramp oscillator. Since this circuit provides a constant-current, it creates a proper straight-slope ramp wave, which sounds 'warmer' than the curved ramp of a resistor. (See Fig.22 and Fig.23). TR3 is the temperature-compensation transistor. A linear tuning pot is used to control the frequency, which is converted to an exponential control. Normally, if a linear pot is used with a linear oscillator then all the subjective frequency change occurs in the first few degrees of rotation. With this circuit, a massive musically correct sweep is obtained. Another control voltage from a keyboard or other source is also mixed in at TR2's base. Heating TR3 gives a pitch drift downwards, the opposite to the exponentiator transistor. To deal with the other smaller source of temperature drift (a slope change which causes the scaling to go out) a special positive-temperature-coefficient resistor of +3300ppm/°C is usually used in the control input attenuator for R11.

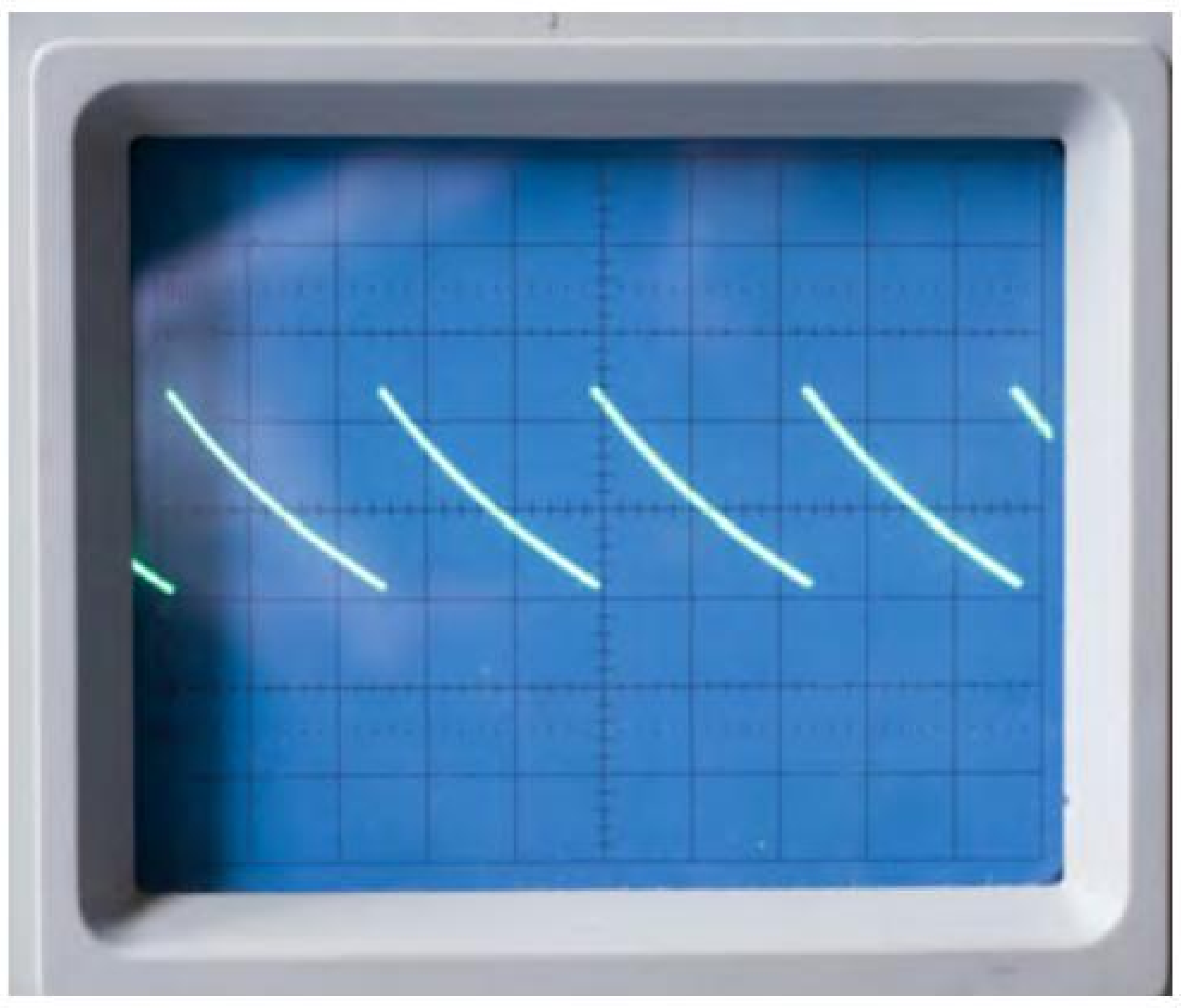


Fig.22. Curved ramp characteristic of resistive charging of a capacitor in ramp oscillator. (Photo: Harvey Rothman)

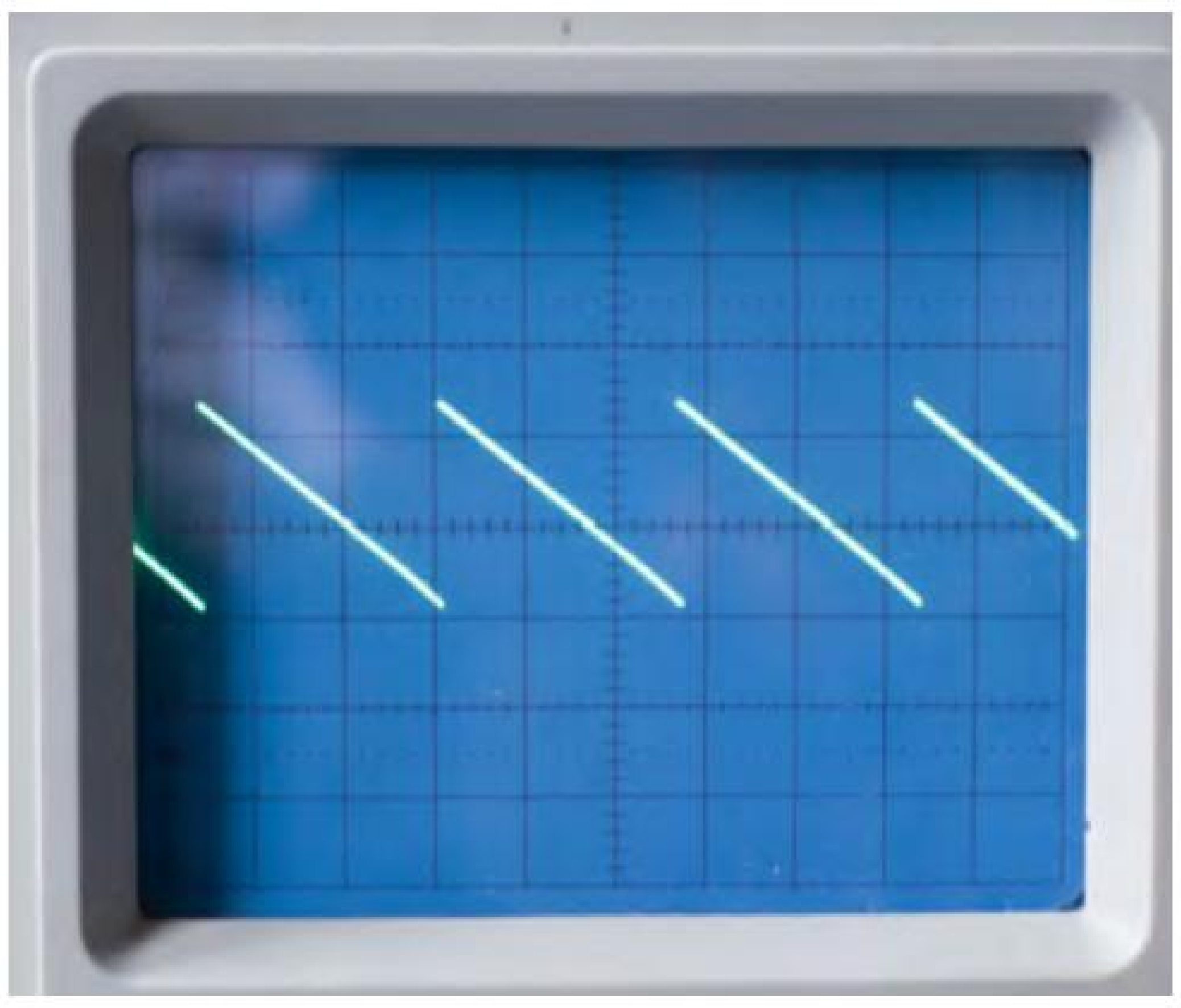


Fig.23. Superior straight ramp with constant-current charging. (Photo: Harvey Rothman)

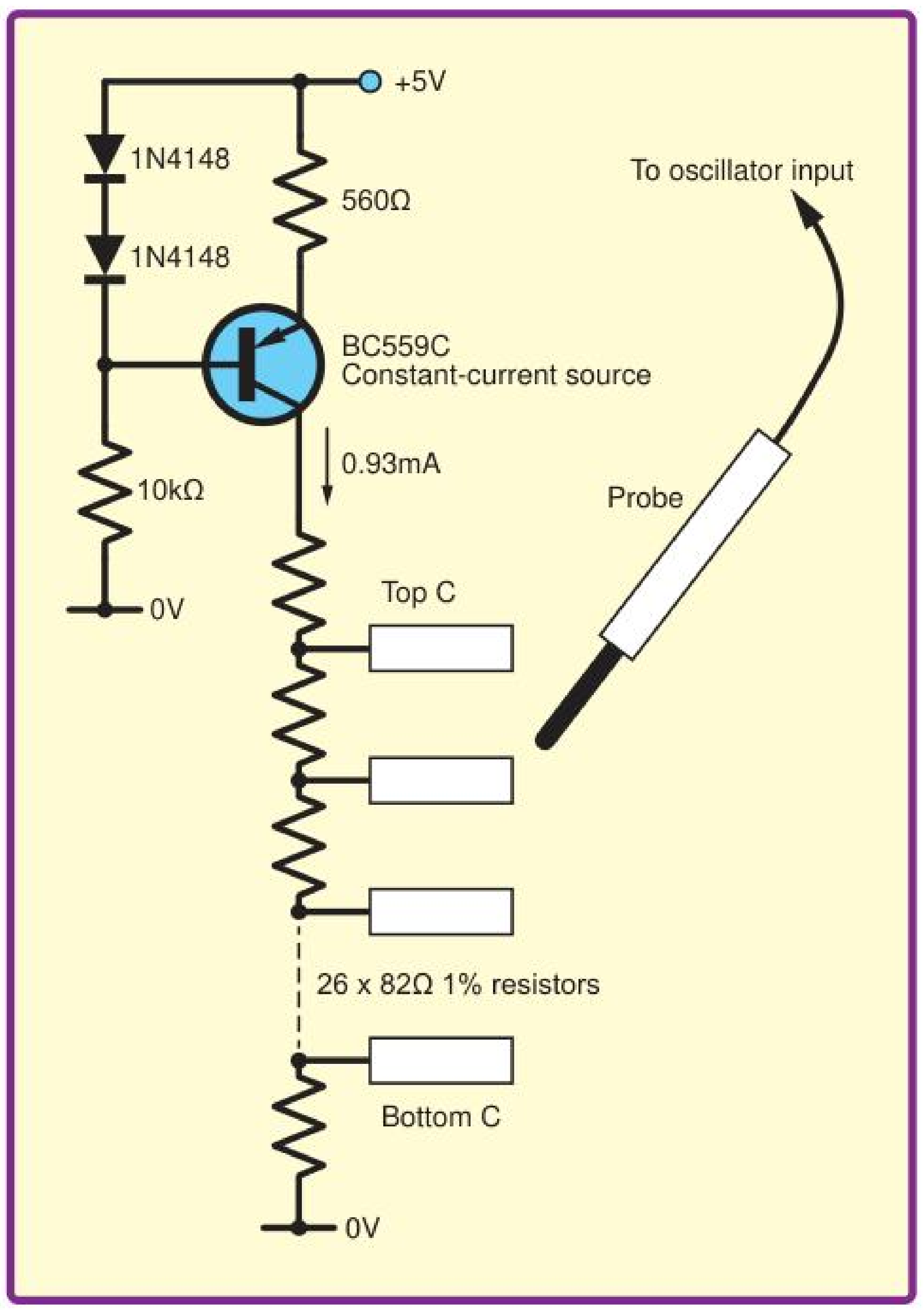

+5V
1N4148
1N4148
560Ω
To oscillator input
BC559C Constant-current source
0.93mA
10kΩ
Probe
0V
Top C
26 x 82Ω 1% resistors
Bottom C
0V

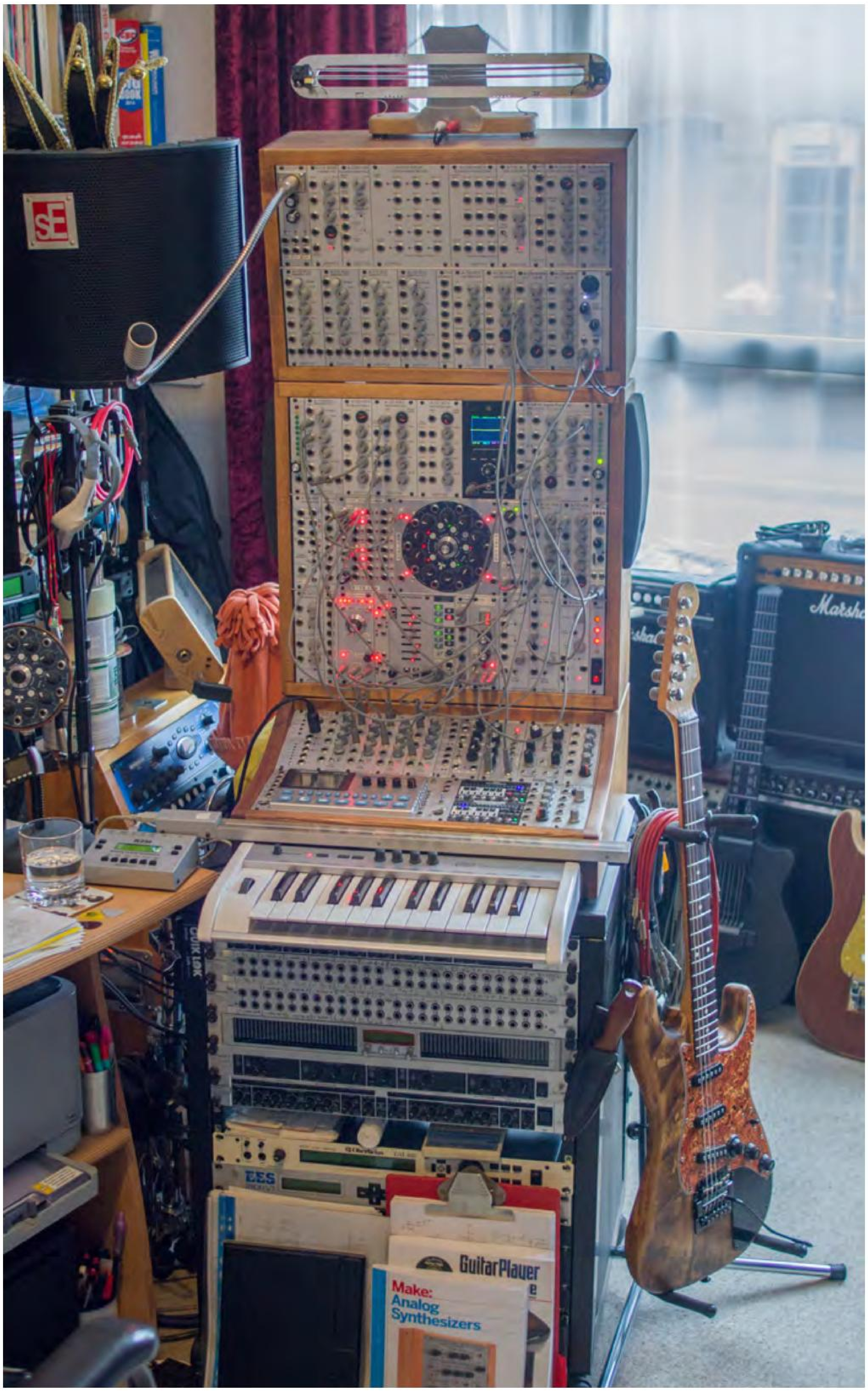
Fig.24. Linear 1V/octave keyboard suitable for use with an exponentiator circuit.

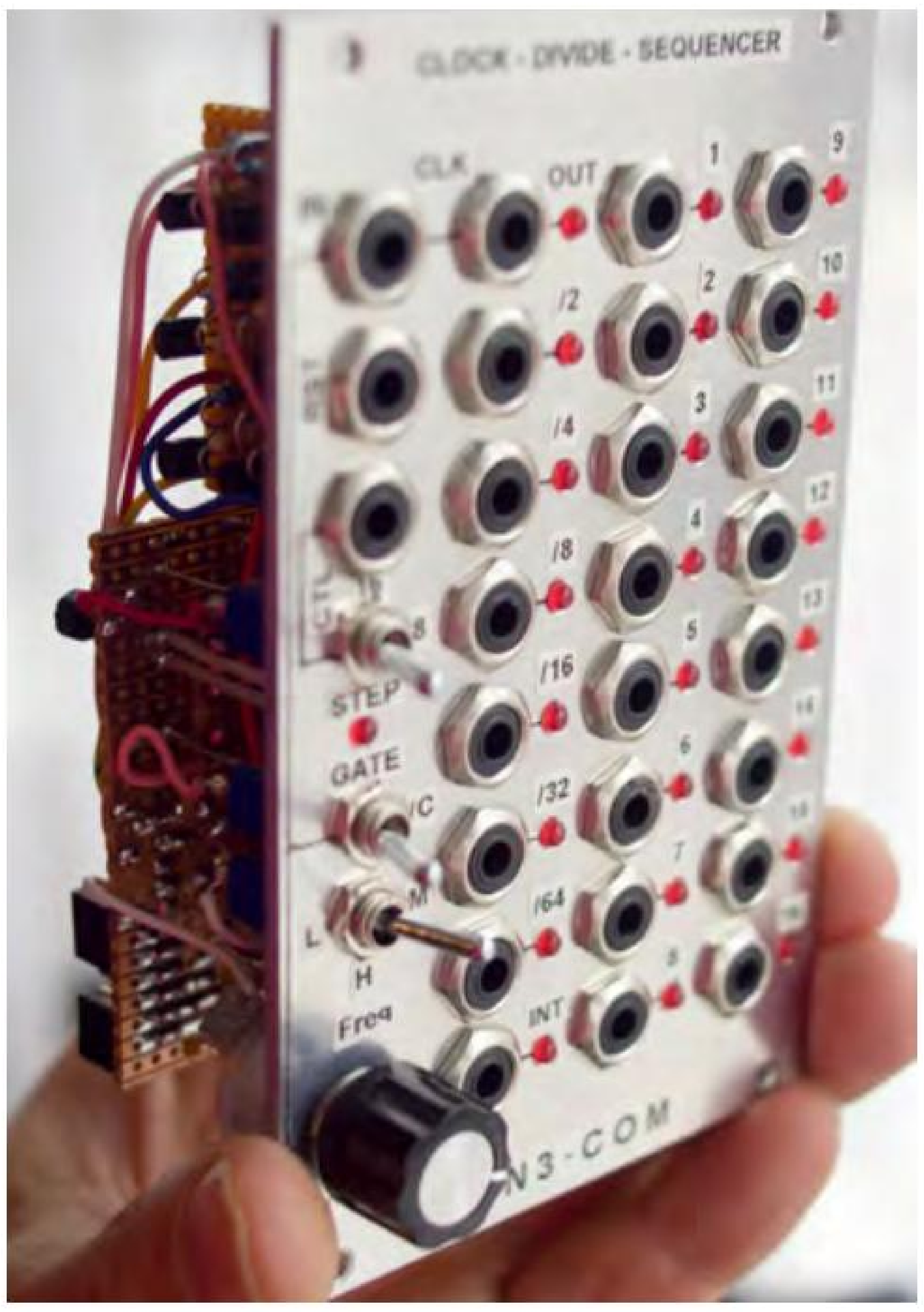
Linear keyboard

To play notes with this exponentiator a linear 1V/octave keyboard is needed, as shown in Fig.24. A resistor chain is fed from a 1mA current source, which in conjunction with 82Ω resistors gives almost the required 83mV per semitone (this figure is obtained by dividing 1V by 12, the number of notes in an octave). VR1 is the tuning control and PR1 is the scale adjustment to ensure the spacing of the notes is correct. Note that adjusting this control is difficult because the pitch changes at the same time. However, if you have perfect pitch hearing or a frequency counter it is no problem to set the octaves.

Unlike the low-power 'Stylophone' which is gated on and off by the stylus, this oscillator runs continuously and between notes it will jump to an arbitrary frequency. To avoid this problem and to provide a gate signal to other parts of the synthesiser I'll describe some additions to the keyboard circuit in *Part 2* next month. Also, some other essential synth circuit blocks will be described, such as a sample and hold, envelope generators and voltage-controlled amplifiers. With these blocks and the GenX-1 voltage-controlled filter, previously described in *Variable Filters Part 2* in *EPE* (May 2018), a complete low-cost analogue synthesiser can be built along the lines of Fig.15.

Before signing off this month, I'd just like to (visually) revisit Grant Steven's superb analogue synthesiser, shown earlier in Fig.2. It really is an impressive piece of equipment and even includes a springline reverb. (See the module described in the April 2018 issue to get an appreciation of this ingenious analogue effect.) See Fig.25 to Fig.28 opposite.




CLOCK - DIVIDE - SEQUENCER
CLK
OUT
/2
/4
/8
/16
/32
/64
STEP
GATE
Freq
INT
N3-COM

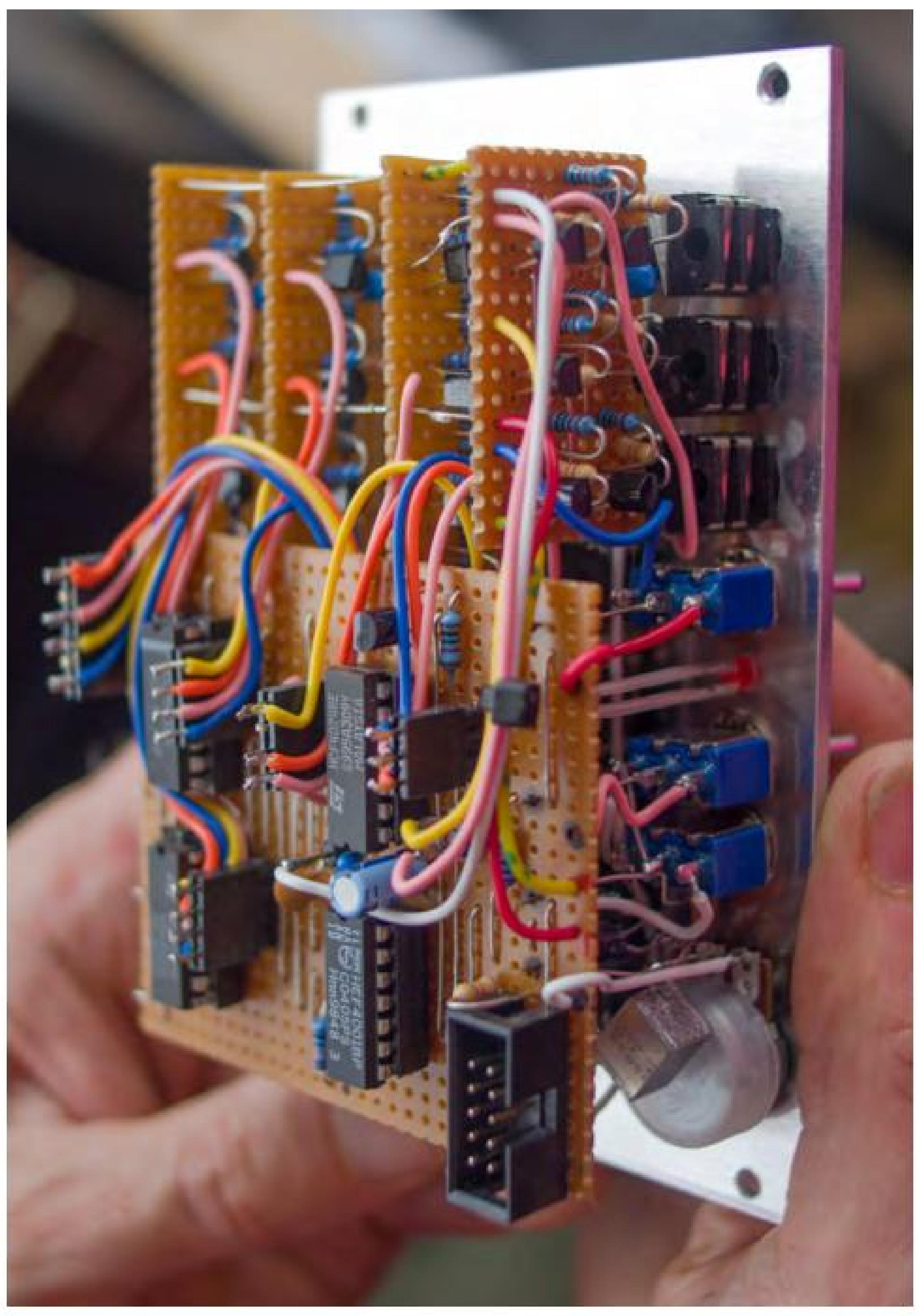
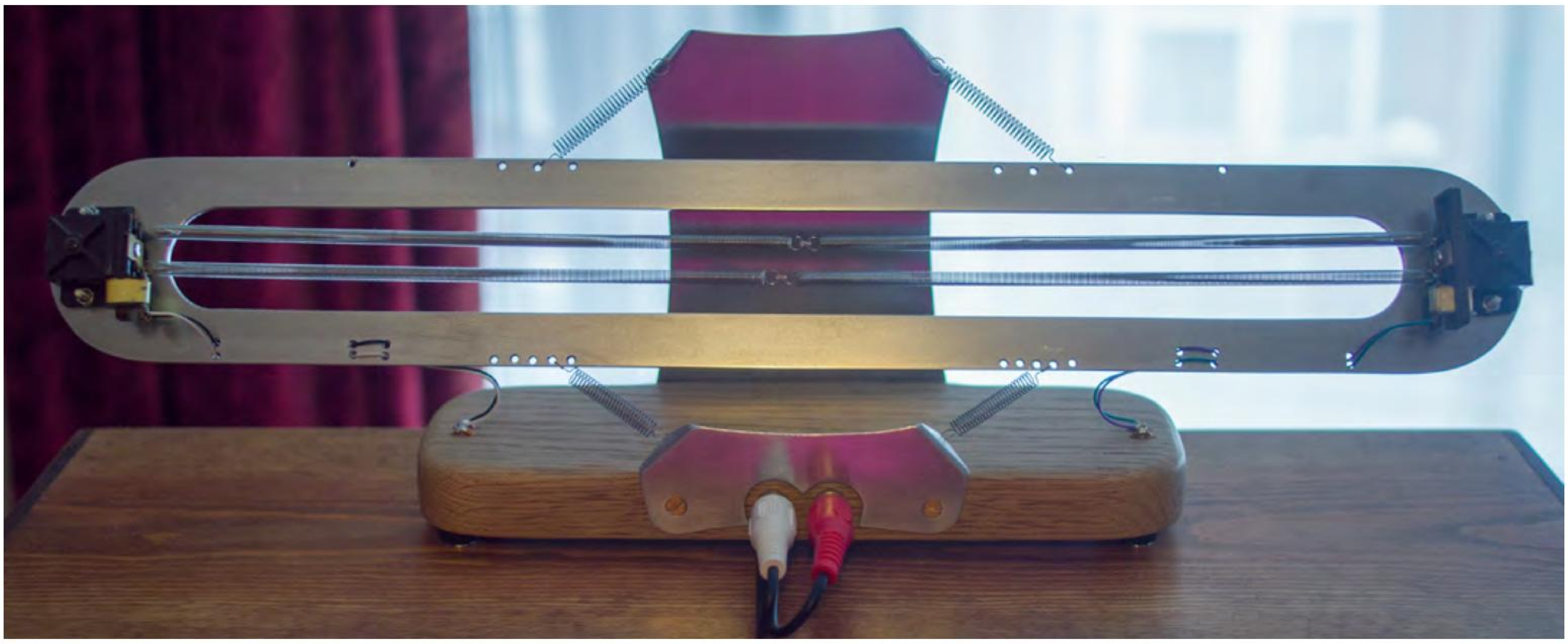


Fig.25. (top left) Grant Steven's analogue synthesiser; Fig.26 and Fig.27 (above) front and rear views of a 'Clock-Divide-Sequencer' unit; and Fig.28 (below) Springline reverb unit. (All photos: Harvey Rothman)



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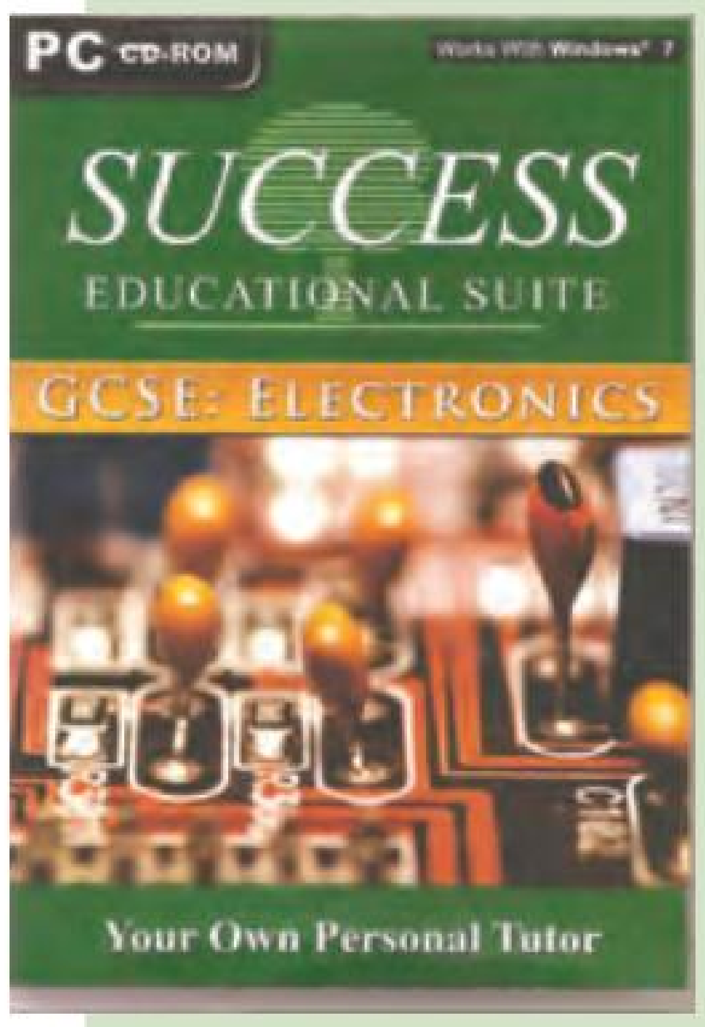

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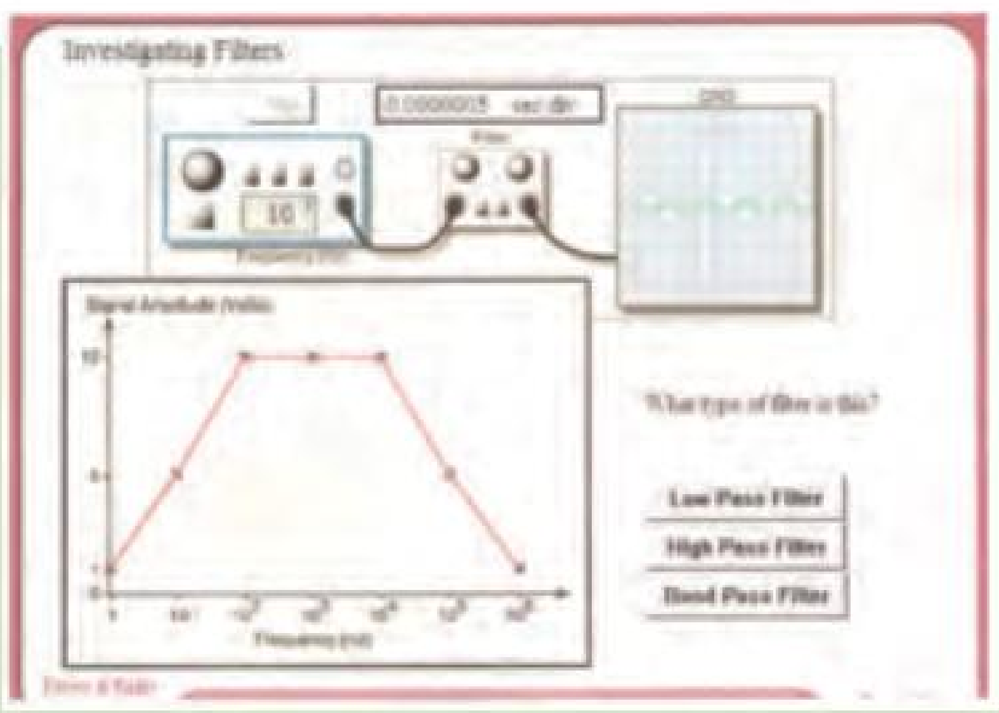

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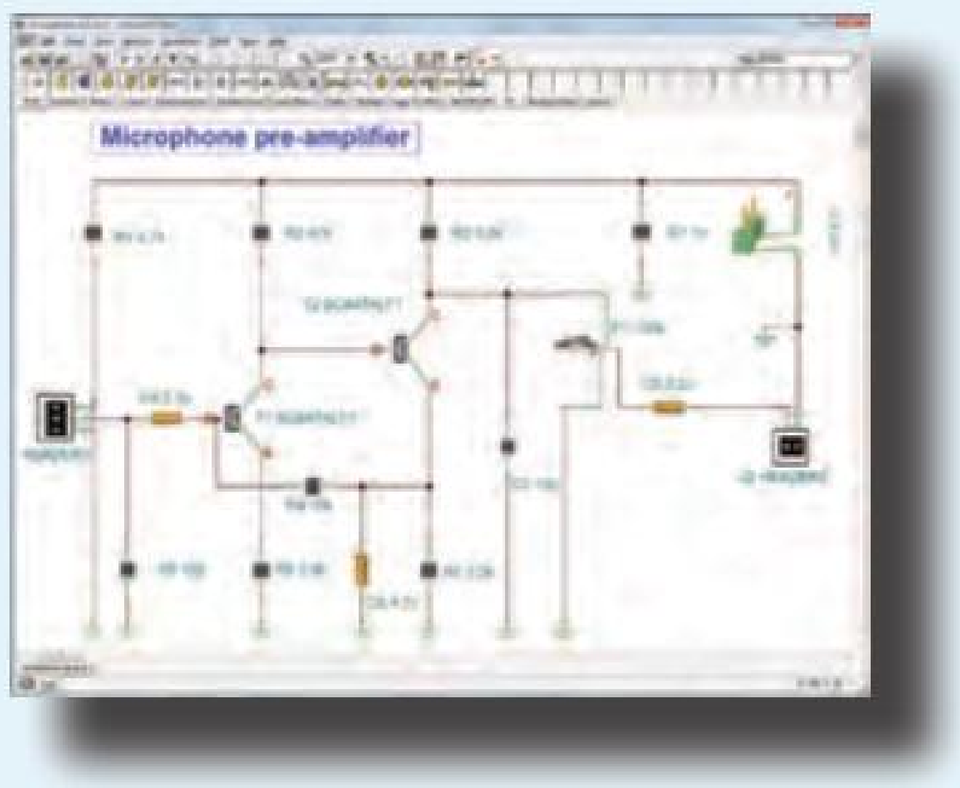

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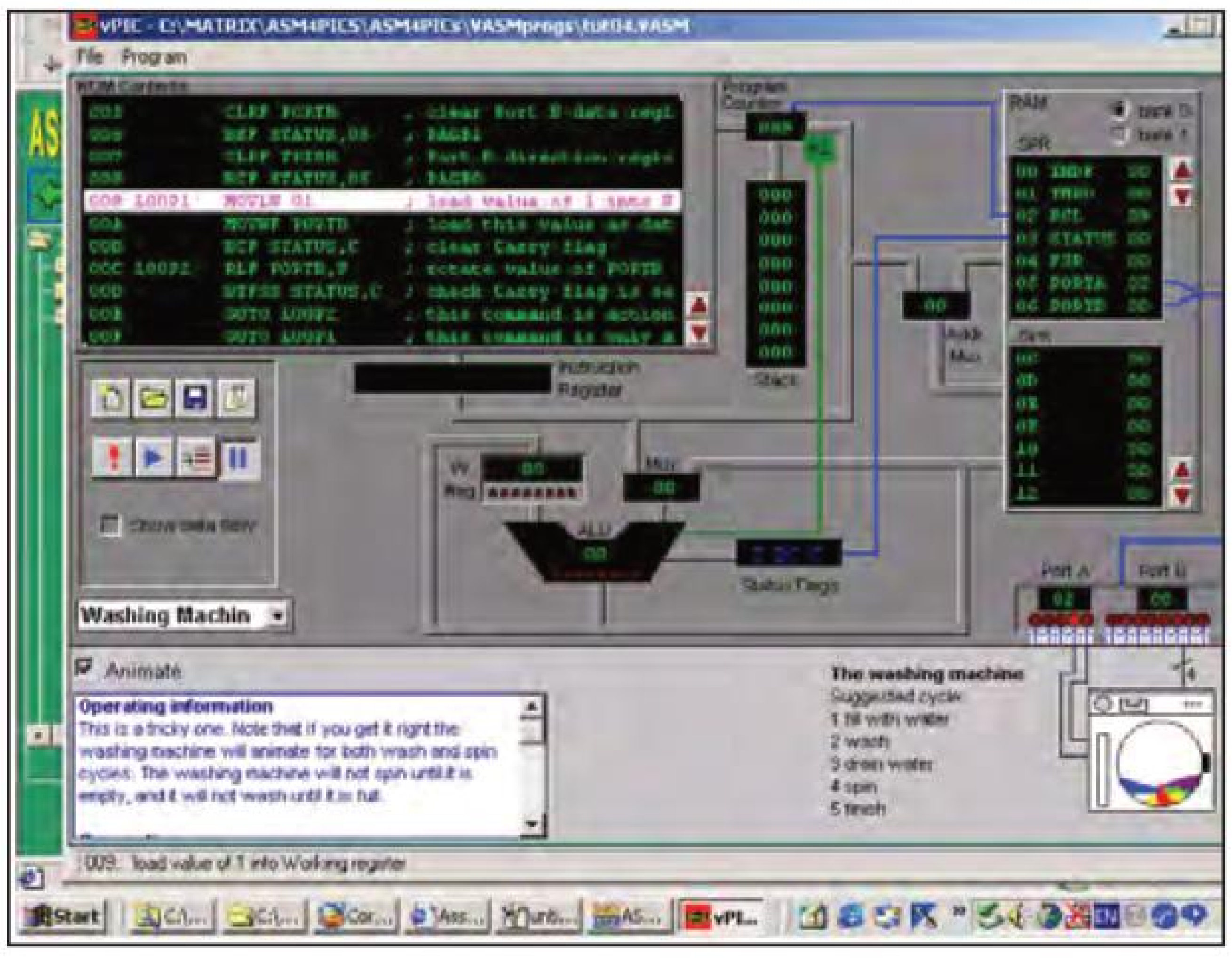

Operating information
This is a tricky one. Note that if you get it right the washing machine will animate for both wash and spin cycles. The washing machine will not spin until it is empty, and it will not wash until it is full.

The washing machine
Suggested cycle
1 fill with water
2 wash
3 drain water
4 spin
5 finish

009: load value of 1 into Working register

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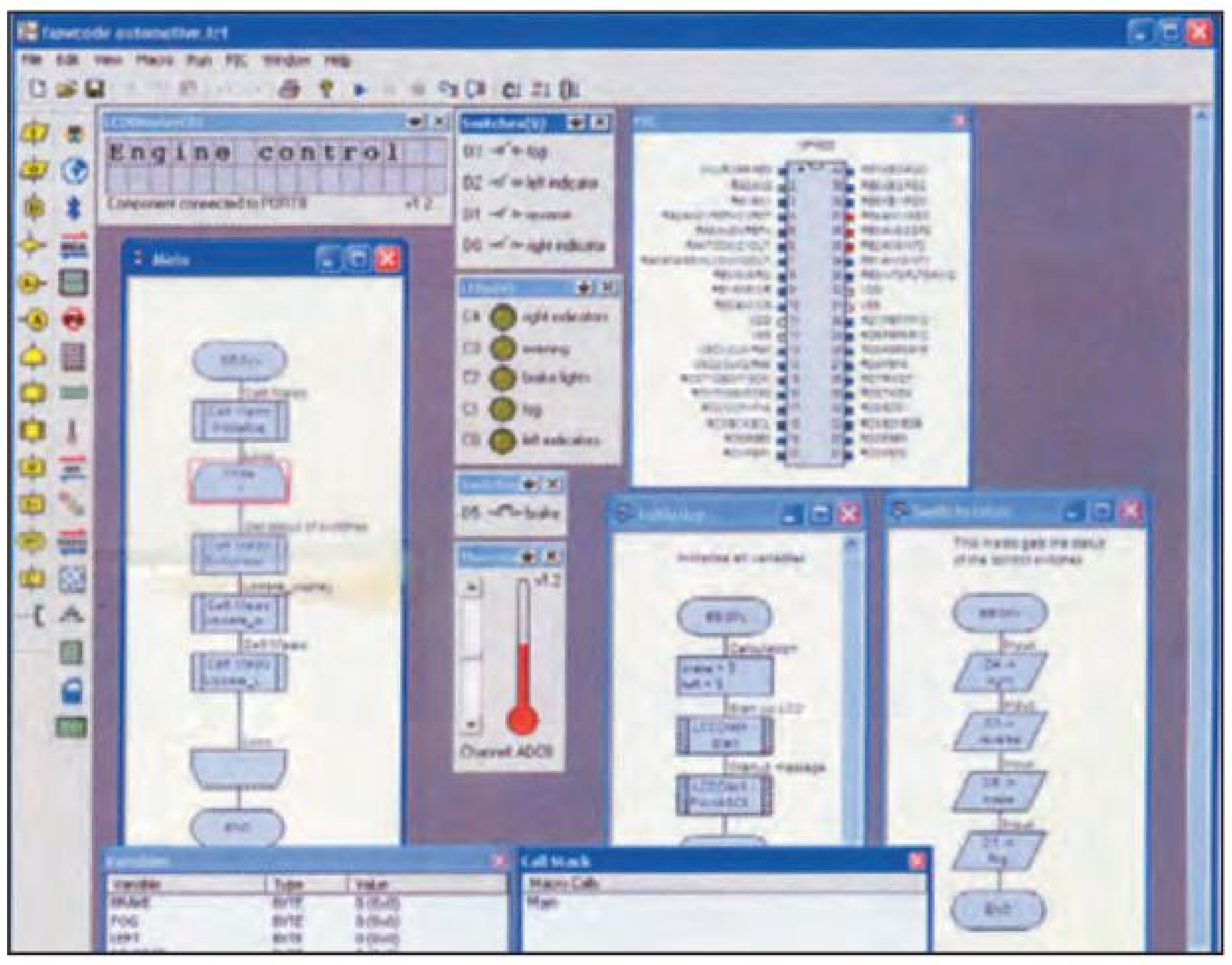

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Teach-In 2017

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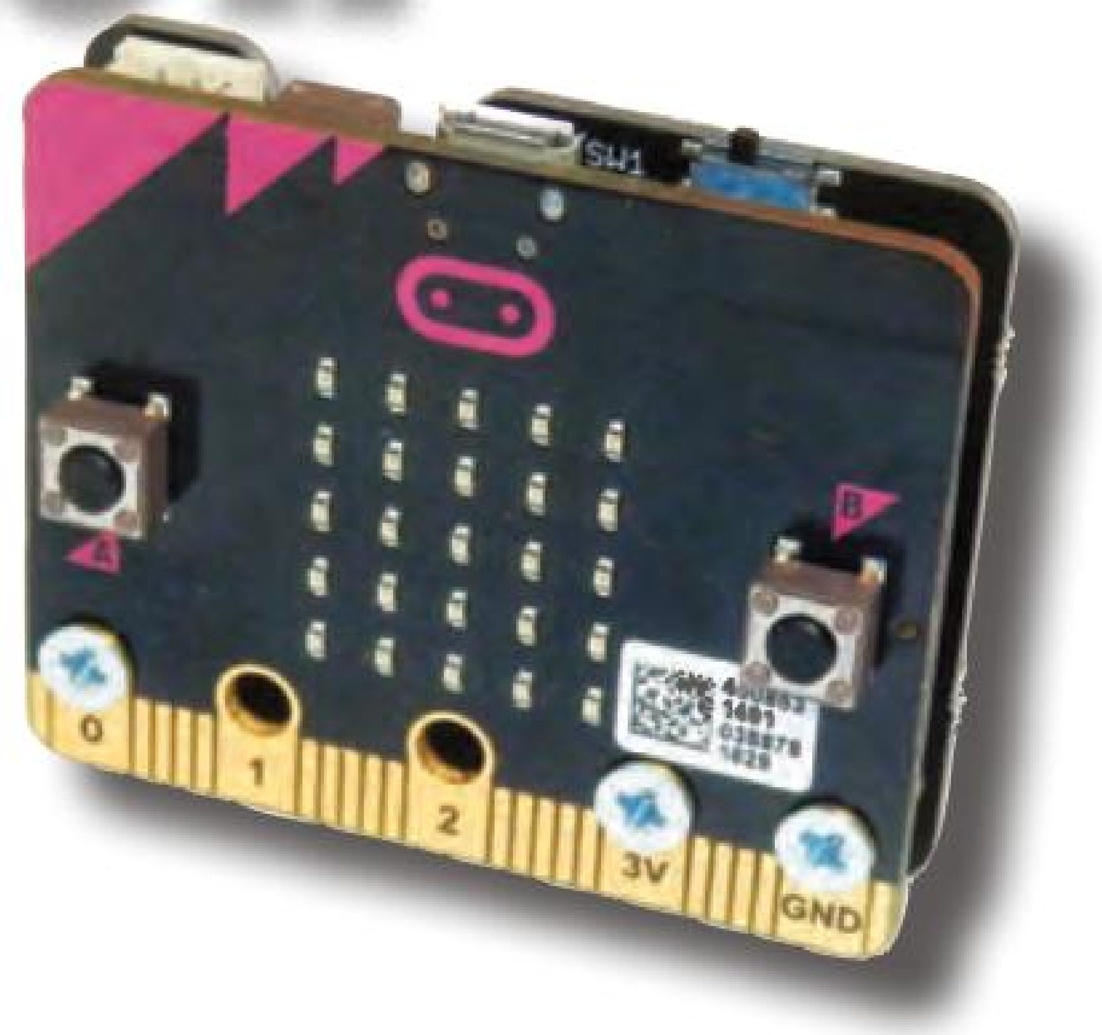

NEW
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Python Coding on the BBC micro:bit
Jim Gatenby

PYTHON CODING ON THE BBC MICRO:BIT

Jim Gatenby

Python is the leading programming language, easy to learn and widely used by professional programmers. This book uses MicroPython, a version of Python adapted for the BBC Micro:bit.

Among the many topics covered are: The main features of the BBC micro:bit including a simulation in a Web browser screen; The various levels of programming languages; The Mu Editor for writing, saving and retrieving programs, with sample programs and practice exercises; REPL, an interactive program for quickly testing lines of code; Scrolling messages, creating and animating images on the micro:bit's LEDs; Playing and creating music, sounds and synthesized speech; Using the on-board accelerometer to detect movement of the micro:bit on three axes; A glossary of computing terms.

This book is written using plain English and avoiding technical jargon wherever possible and covers many of the coding instructions and methods which are common to most programming languages. It should be helpful to beginners of any age, whether planning a career in computing or writing code as an enjoyable hobby.

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For Beginners of Any Age
Getting Started with the BBC micro:bit
Mike Tooley

GETTING STARTED WITH THE BBC MICRO:BIT

Mike Tooley

Not just an educational resource for teaching youngsters coding, the BBC micro:bit is a tiny low cost, low-profile ARM-based single-board computer. The board measures 43mm × 52mm but despite its diminutive footprint it has all the features of a fully fledged microcontroller together with a simple LED matrix display, two buttons, an accelerometer and a magnetometer.

Mike Tooley's book will show you how the micro:bit can be used in a wide range of applications from simple domestic gadgets to more complex control systems such as those used for lighting, central heating and security applications. Using Microsoft Code Blocks, the book provides a progressive introduction to coding as well as interfacing with sensors and transducers.

Each chapter concludes with a simple practical project that puts into practice what the reader has learned. The featured projects include an electronic direction finder, frost alarm, reaction tester, battery checker, thermostatic controller and a passive infrared (PIR) security alarm.

No previous coding experience is assumed, making this book ideal for complete beginners as well as those with some previous knowledge. Self-test questions are provided at the end of each chapter, together with answers at the end of the book. So whatever your starting point, this book will take you further along the road to developing and coding your own real-world applications.

108 Pages **Order code BBC MBIT** **£7.99**

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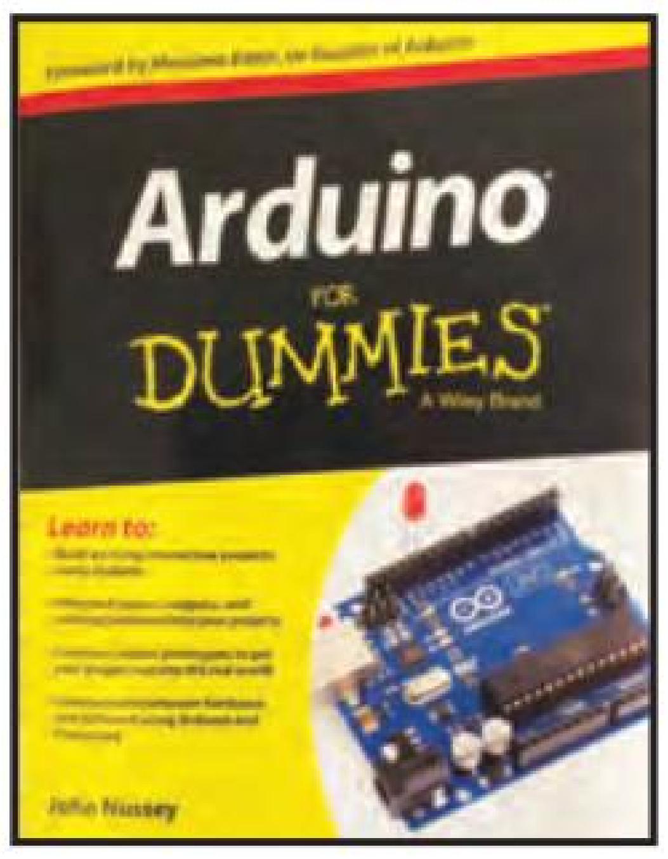
Teach-In 2016

Exploring the Arduino



ARDUINO FOR DUMMIES

John Nussey

Arduino is no ordinary circuit board. Whether you're an artist, a designer, a programmer, or a hobbyist, Arduino lets you learn about and play with electronics. You'll discover how to build a variety of circuits that can sense or control real-world objects, prototype your own product, and even create interactive artwork. This handy guide is exactly what you need to build your own Arduino project – what you make is up to you!

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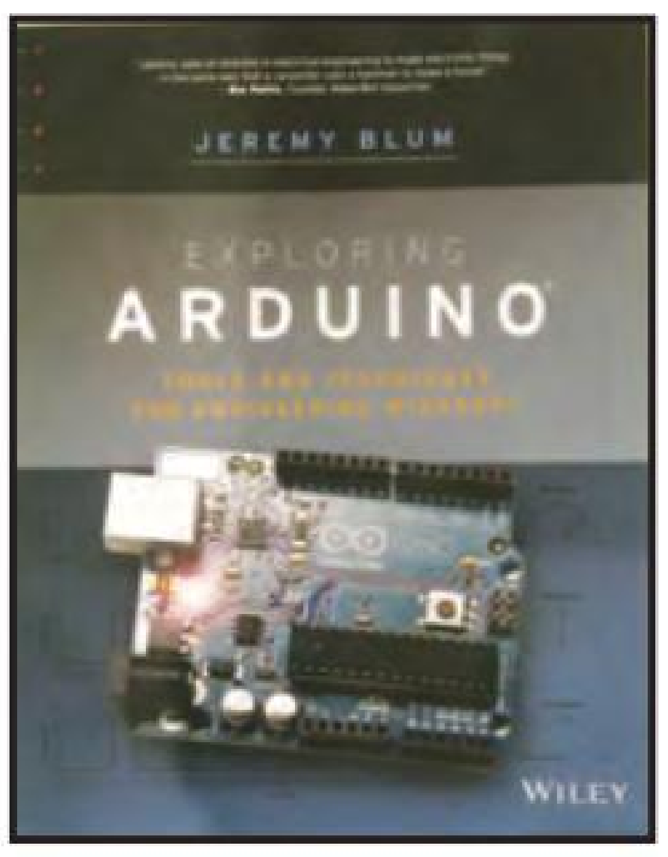

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Jeremy Blum

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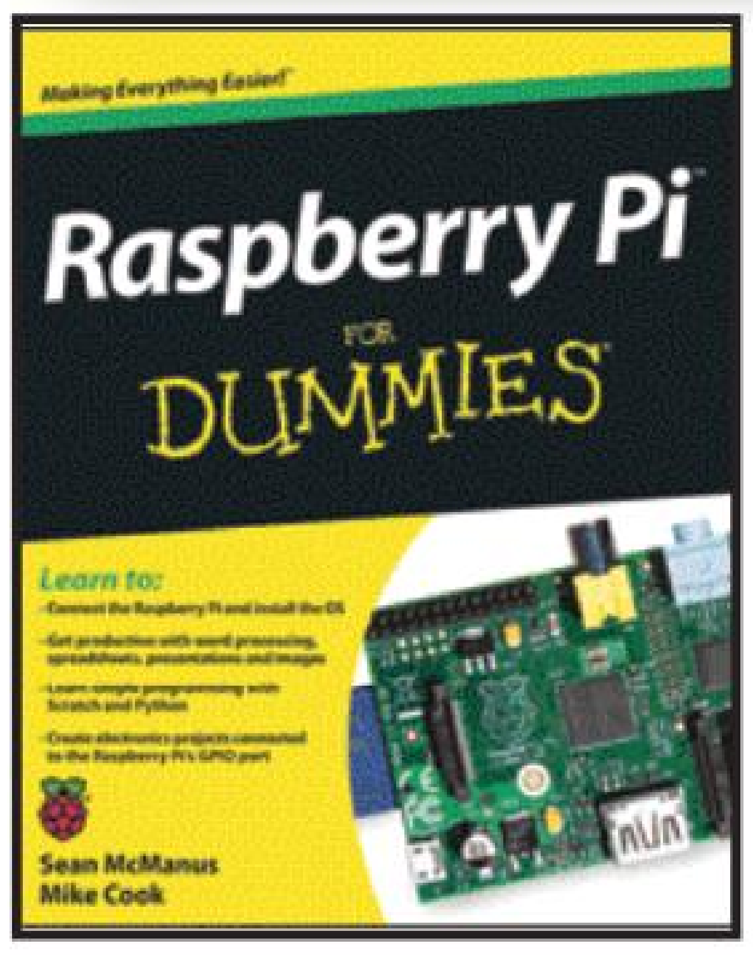

RASPBERRY Pi FOR DUMMIES

Sean McManus and Mike Cook

Write games, compose and play music, even explore electronics – it's easy as Pi! The Raspberry Pi offers a plateful of opportunities, and this great resource guides you step-by-step, from downloading, copying, and installing the software to learning about Linux and finding cool new programs for work, photo editing, and music. You'll discover how to write your own Raspberry Pi programs, create fun games, and much more! Open this book and find: What you can do with Python; Ways to use the Raspberry Pi as a productivity tool; How to surf the web and manage files; Secrets of Sonic Pi music programming; A guide to creating animations and arcade games; Fun electronic games you can build; How to build a 3D maze in Minecraft; How to play music and videos on your Raspberry Pi.

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ONLY AVAILABLE ON CDROM

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Mike & Richard Tooley

Teach-In 6 contains an exciting series of articles that provides a complete introduction to the Raspberry Pi, the low cost computer that has taken the education and computing world by storm.

This latest book in our Teach-In series will appeal to electronic enthusiasts and computer buffs wanting to get to grips with the Raspberry Pi.

Anyone considering what to do with their Pi, or maybe they have an idea for a project but don't know how to turn it into reality, will find Teach-In 6 invaluable. It covers: Programming, Hardware, Communications, Pi Projects, Pi Class, Python Quickstart, Pi World, Home Baking etc.

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This exciting series has been designed for electronics enthusiasts who want to get to grips with the inexpensive, immensely popular Arduino microcontroller, as well as coding enthusiasts who want to explore hardware and interfacing. Teach-In 8 will provide a one-stop source of ideas and practical information.

The Arduino offers a remarkably effective platform for developing a huge variety of projects; from operating a set of Christmas tree lights to remotely controlling a robotic vehicle through wireless or the Internet. Teach-In 8 is based around a series of practical projects with plenty of information to customise each project.

This book also includes *PIC n' Mix*: PICs and the PICkit 3 - A Beginners guide by Mike O'Keefe and *Circuit Surgery* by Ian Bell - State Machines part 1 and 2.

The Free CDROM includes files for Teach-In 8 plus Microchip MPLAB, IDE, XC8 8-bit Compiler and PICkit 3 User Guide. Also included is Lab-Nation Smartscope software.

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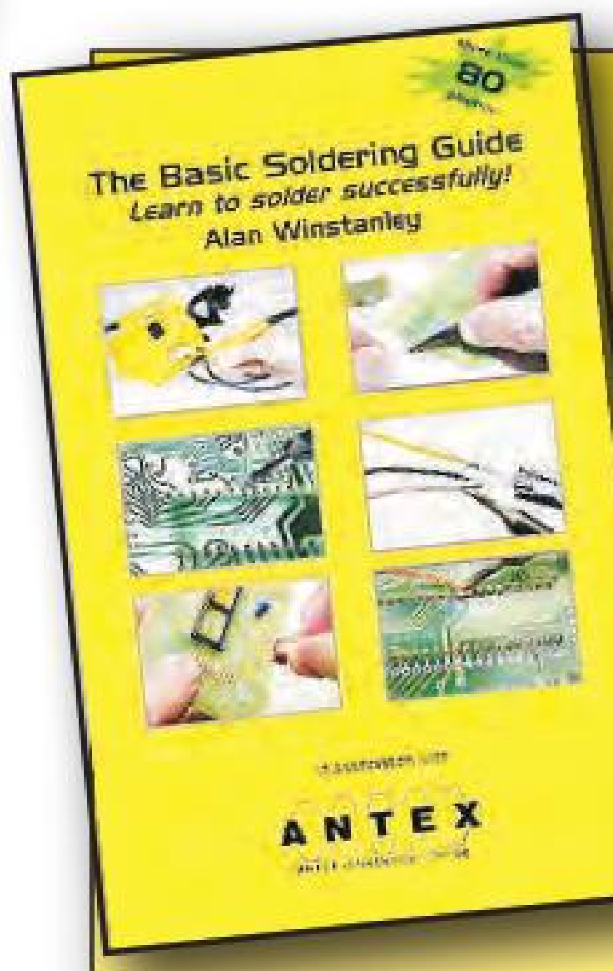

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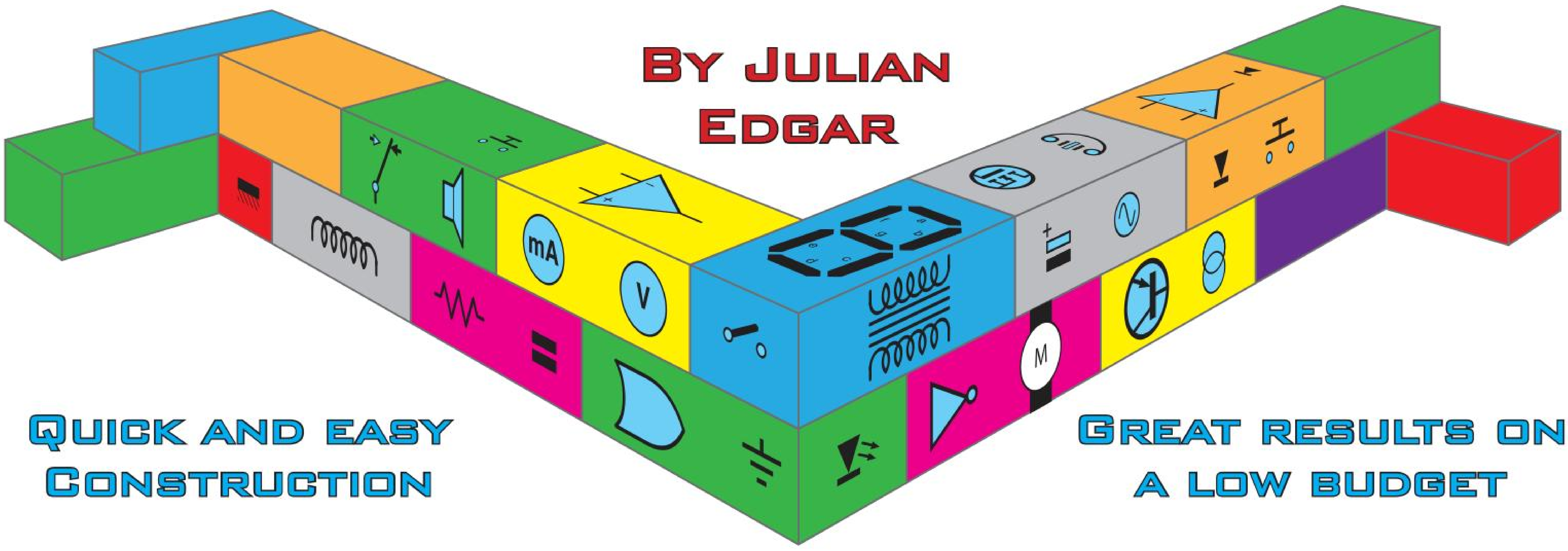

BY JULIAN EDGAR

QUICK AND EASY CONSTRUCTION

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SIMPLE REMOTE CONTROL

Large complex projects are fun, but they take time and can be expensive. Sometimes you just want a quick result at low cost. That's where this series of *Electronic Building Blocks* fits in. We use 'cheap as chips' components bought online to get you where you want to be... FAST! They represent the best value we can find in today's electronics marketplace!

This month's *Electronic Building Block* is a super-useful, very low-cost remote control system with a two-button key fob and relay output.

These days, we've got used to using remotes all the time. Remotes for car door unlocking, for the TV and audio gear, even for lights and fans; but what if you have a distant item that you want to turn on and off – and it doesn't have a remote? For example, you have a dark place in your yard and you'd like to be able to turn on a light – without having to run new wiring back to the house. Or you'd like a simple burglar alarm in your shed or outhouse, an alarm you can switch off by using the remote.

Well, here's a simple and effective remote control. It's incredibly cheap (under £4 delivered), uses a relay output and has three different operating modes. The key fob remote also looks half-decent and has simple 'on' and 'off' pushbuttons. The unit comprises a small box that is 63 × 32 × 20mm, and the keyfob is 63 × 34 × 15mm.

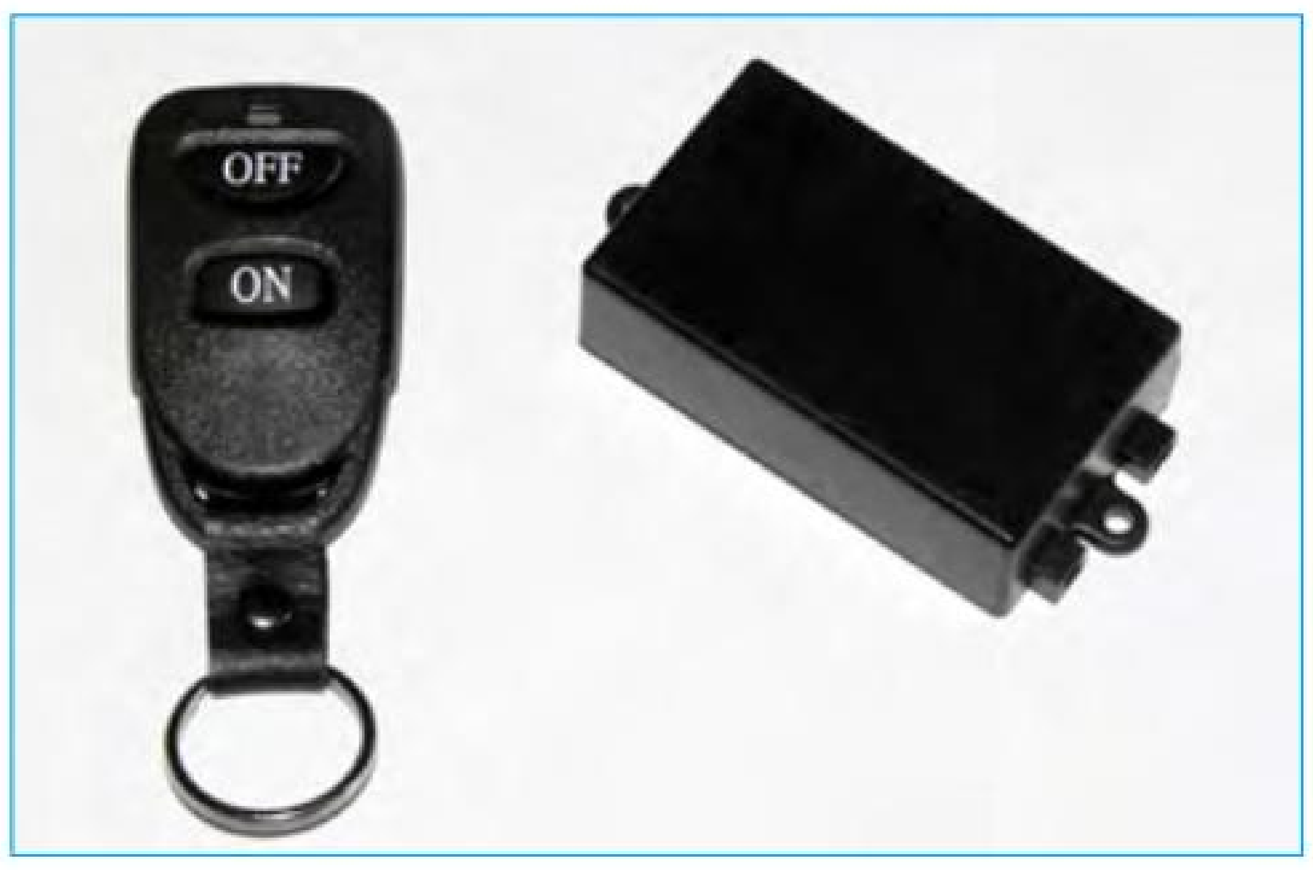


Fig.1. This remote control system is easy to wire into place (it uses a relay output) and works at distances of up to 30m.

The system is available from **www.banggood.com** – search under 'Geekcreit DC 12V 10A Relay 1CH Channel Wireless RF Remote Control Switch Transmitter With Receiver'.

Wiring

Wiring is very easy. The main unit is powered by 12V and draws only 40mA, even with the relay activated. I measured 12mA with the relay off, a value that could be lowered a little by removing the on-board LED that stays on whenever power is connected. The low-current draws mean the unit can be powered by any 12V plugpack of the sort you probably already have lying around.

The board is equipped with an SPDT relay that is rated at 10A at 28V DC. (The relay is also rated for mains voltages, but we'd suggest using an external relay if switching mains.) Common, normally open and normally closed screw terminals are provided.

Fig.2. The remote has simple 'on' and 'off' keys that can be configured by an on-board jumper to work in three different ways.

Set up

The system comes with the remote already configured to work with the main module. Extra remotes can be

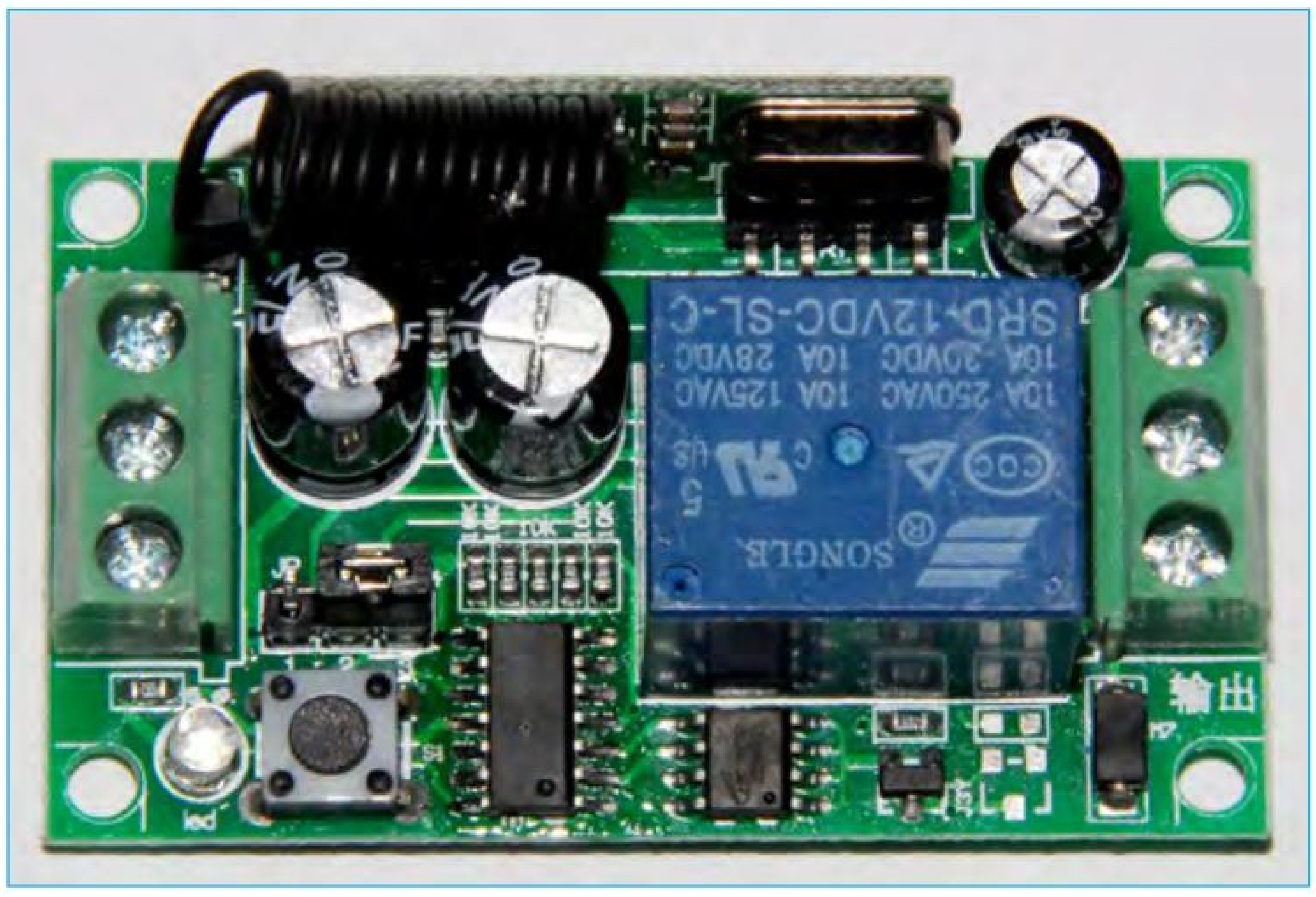


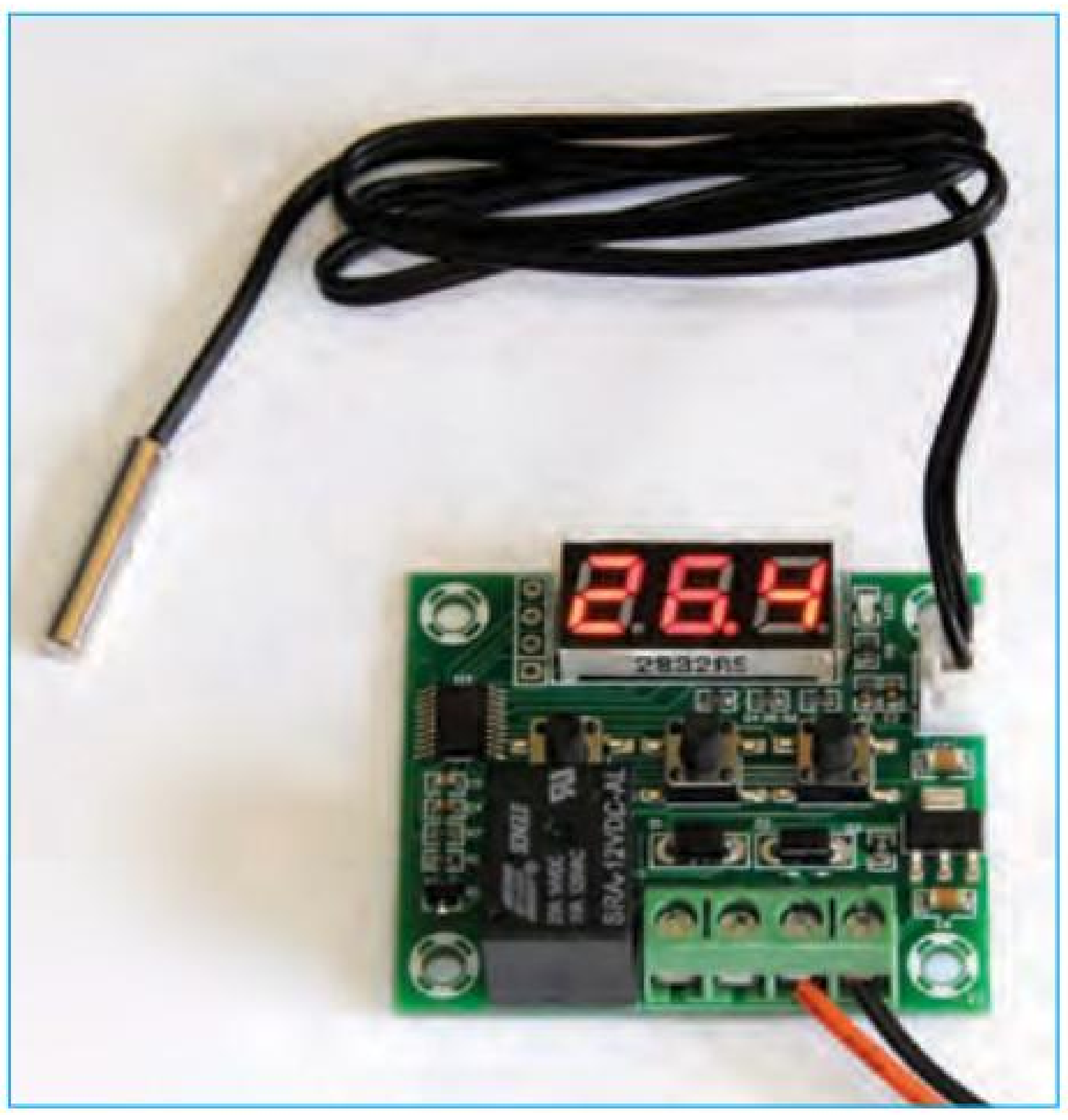
Fig.3. Inside the control module can be seen the jumper that selects different modes, and the press-button used when configuring extra remotes. Up to 12 remotes can be used with the module, although only one is supplied.

purchased (only one is provided) and then the unit is taught to recognise these remotes as well. (Up to 12 remotes can be used.)

Three different modes are available, with these modes selected by the position of an on-board jumper. In position #1 (link to right when the board positioned with the LED at the bottom) the remote works just as you'd expect. Press the 'on' button and the relay activates; press the 'off' button and the relay deactivates. In position #2 (link to left), press the 'on' button once to activate the relay, and press the 'on' button a second time to deactivate the relay. With the link removed, the relay is activated only while the 'on' button is being pressed. These three different modes allow a lot of versatility in how the system is used.

In testing, I found that the remote functioned from anywhere within the house (ie, walls were no problem), and outside it had a range of about 30m when there was clear line-of-sight.

Note that if the relay is activated and power is lost and then regained, the relay does not automatically reactivate. Applications like a burglar alarm should therefore be wired 'fail safe', ie, the alarm is deactivated only with the relay pulled-in.



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All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Tel: 01202 880299; Fax 01202 843233; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.com**. Cheques should be crossed and made payable to *Everyday Practical Electronics* **(Payment in £ sterling only)**.

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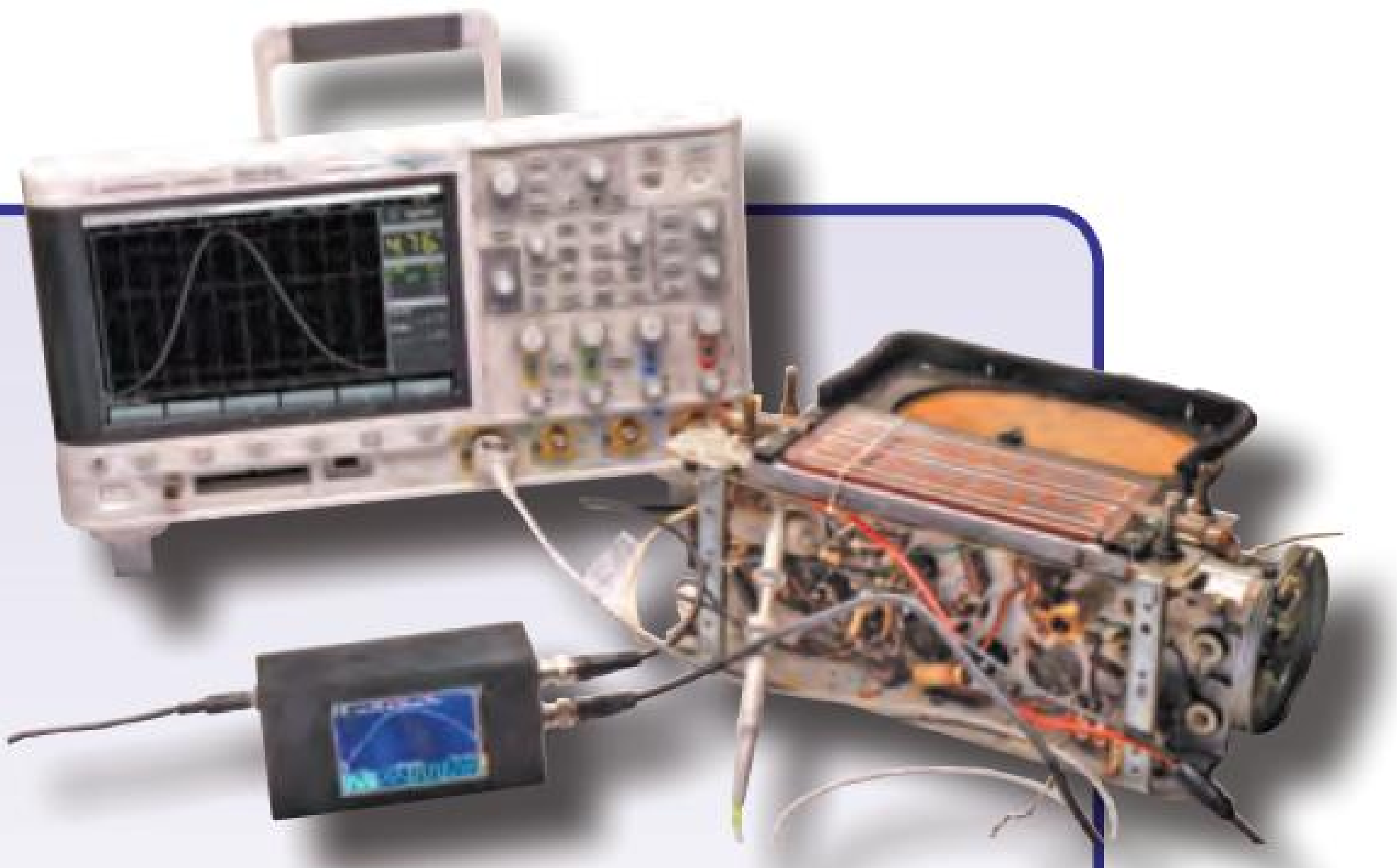
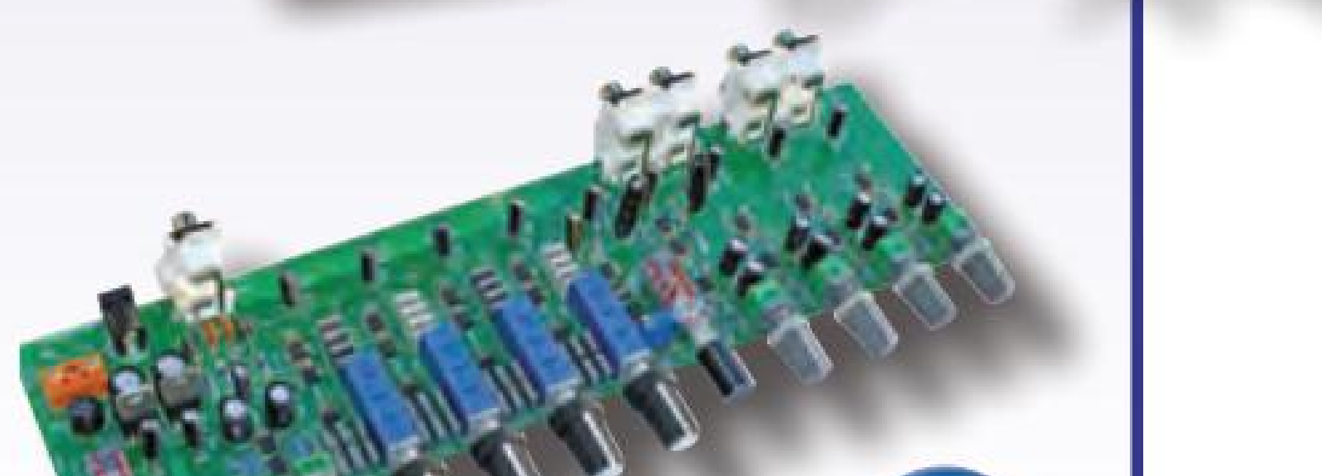
Next Month

Content may be subject to change



Dead-easy Superhet IF Alignment using Direct Digital Synthesis

Don't be put off by the extra-long project name! This super project is based on the touch-screen *Micromite DDS Signal Generator* and makes aligning the IF stage of superhet sets a snap, whether they are valve or transistor-based.



3-Way Fully Adjustable Stereo Active Crossover for Loudspeakers

This *Stereo 3-Way Adjustable Active Crossover* is not only a fantastic tool for loudspeaker design and development, but also it can be integrated into a 2-way or 3-way active (powered) loudspeaker. The crossover points and levels for tweeter, midrange and woofer are fully adjustable with separate controls for each driver.

Ultra-low-voltage Mini LED Flasher

This versatile design uses just a handful of components to flash any colour LED brightly, powered from a single alkaline cell. In fact, it will run off any supply from 0.8V to 3.3V!

Low-cost Electronic Modules – Part 9

In the April issue, we covered the AD9833 Direct Digital Synthesiser (DDS) chip. This time, we're looking at modules based on its big brother, the AD9850. Typically combined with a 125MHz crystal oscillator, it can produce sinewaves to beyond 40MHz, accompanied by a square or pulse waveform. Again, it is SPI controlled.

Touchscreen Appliance Energy Meter – Part 3

In the last two months, we've described how our new *Touchscreen Appliance Energy Meter* works and how to put it together. Having finished assembling the unit, all that's left to do is to calibrate it and start using it.

APPLIANCE ENERGY METER
230VAC 35.8W
0.23A 44.1VA
1.371kWh
$0.37

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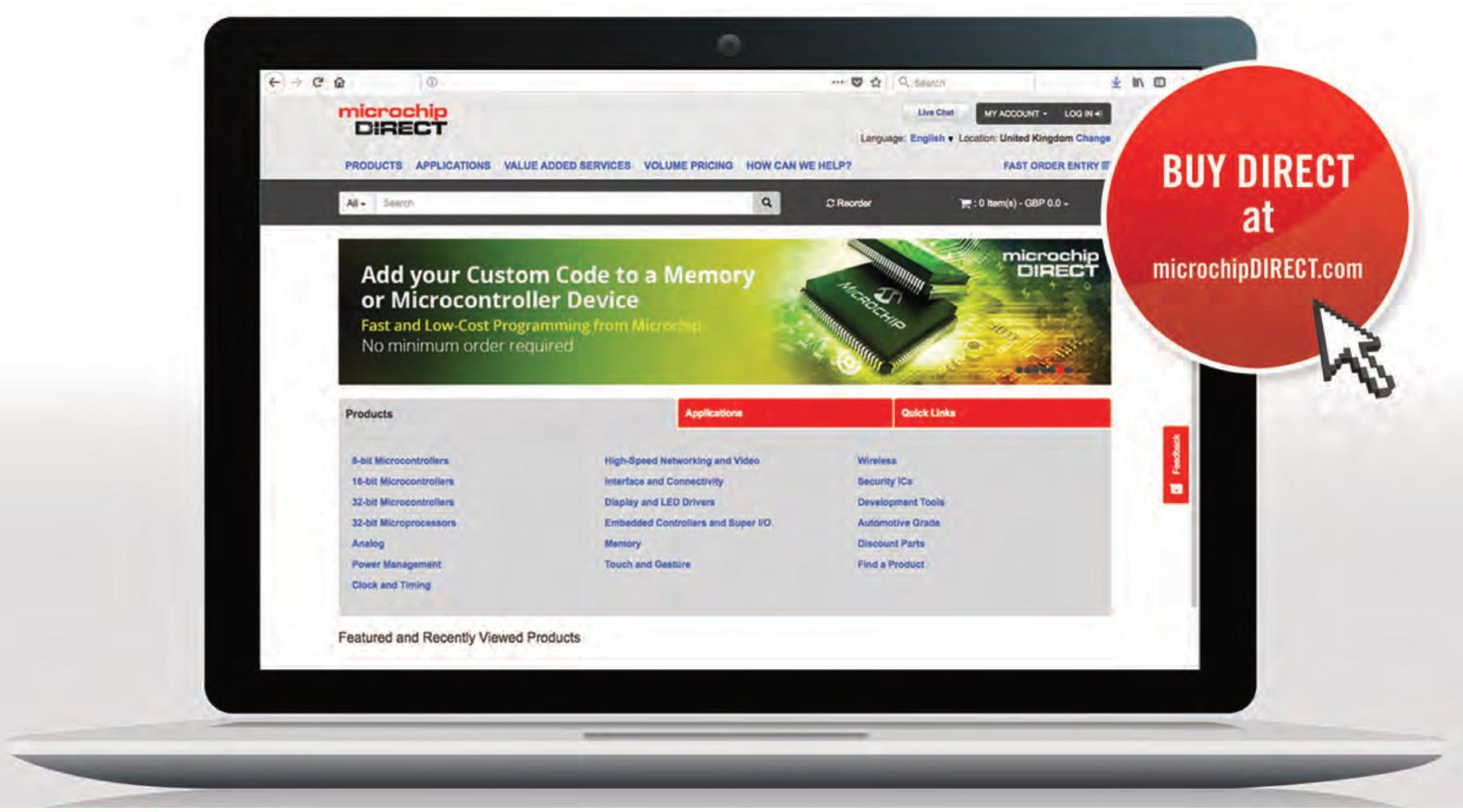
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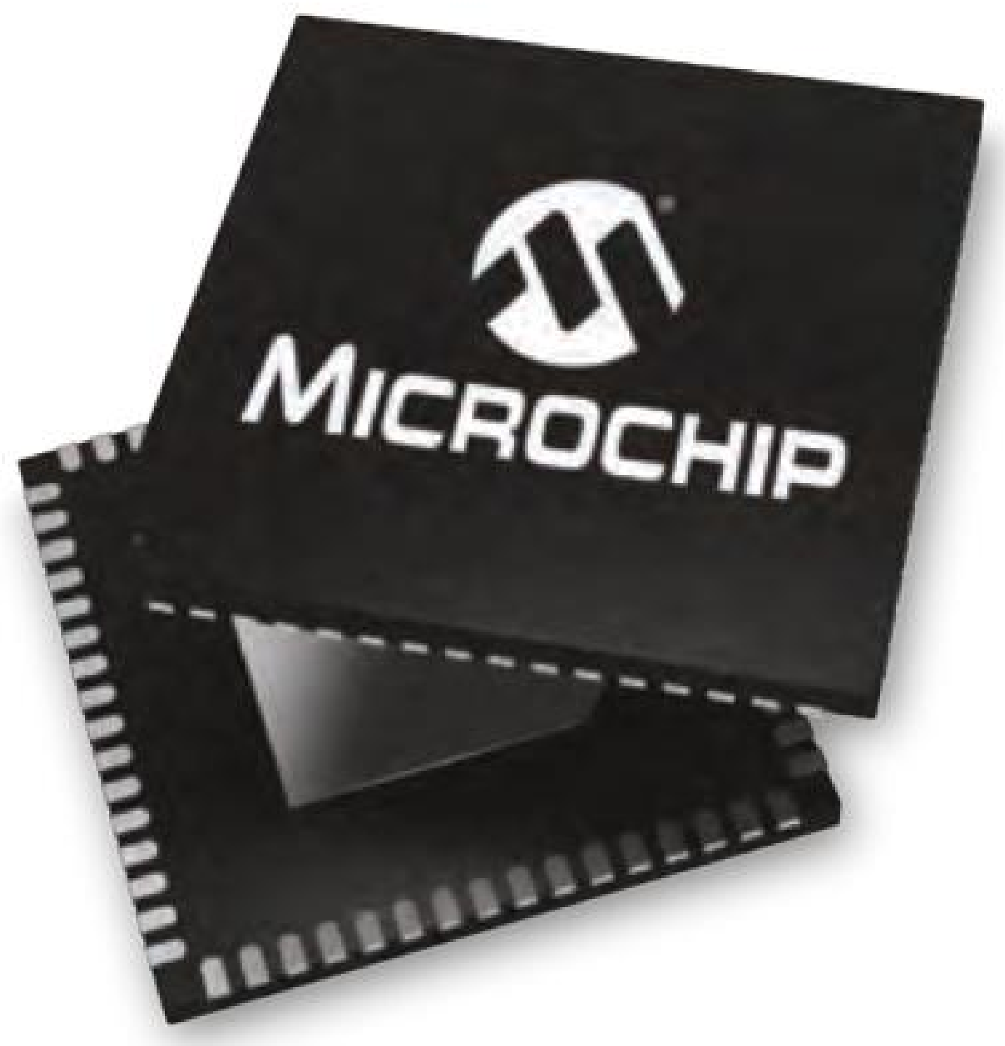

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Slope R=53Ω
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Zener Voltage
Slope Resistance
Selectable Test Currents
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warning: not for in-circuit

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L=701.1µH 15kHz
LCR45
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enter - off
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Component Summary
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L=123.4µH 200kHz

Complex Impedance
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+25.6 +j155.1Ω

Magnitude and Phase
Mag/Phase 200kHz
157.2Ω +80.6°

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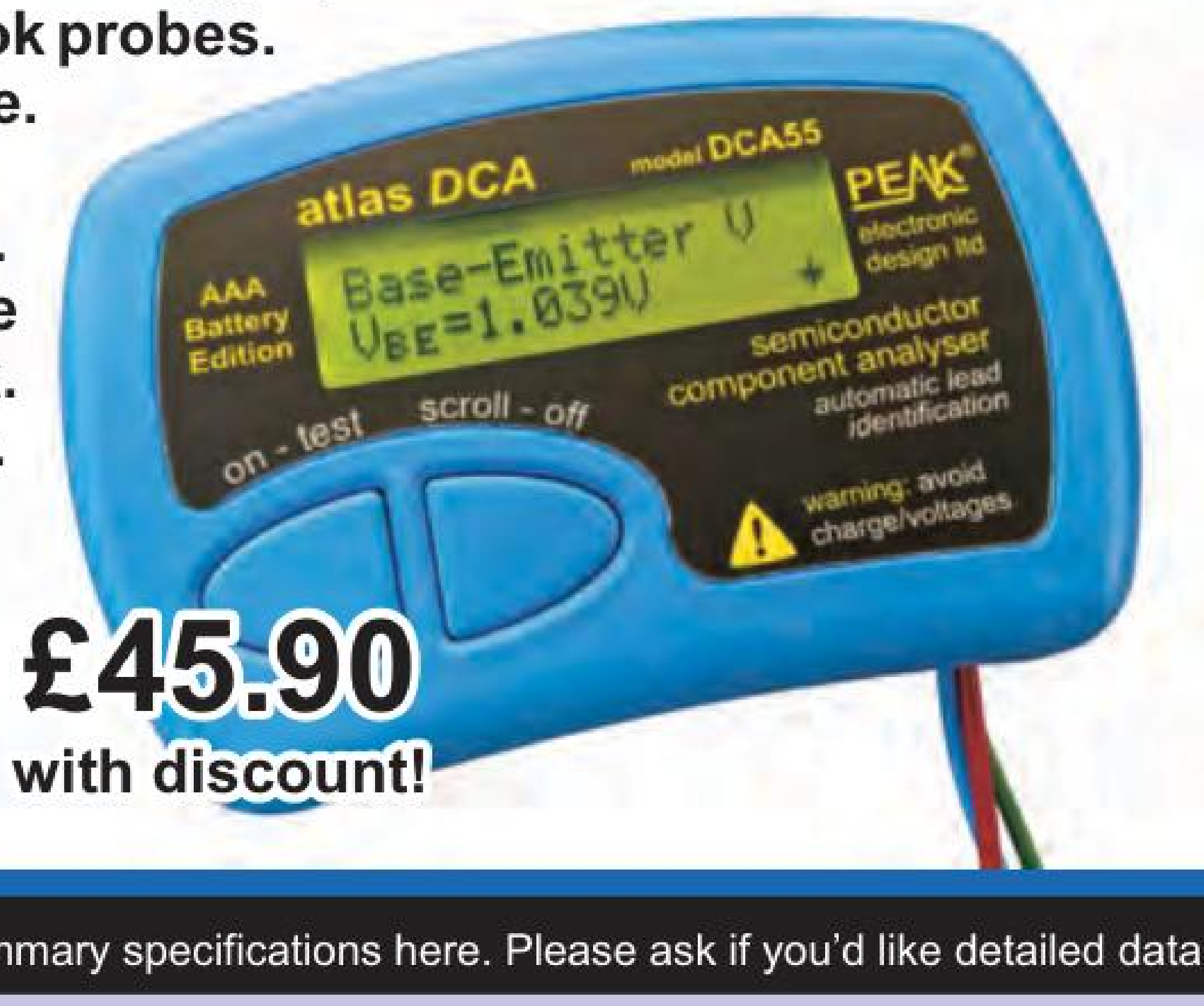
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DCA75
USB + Graphics
PEAK
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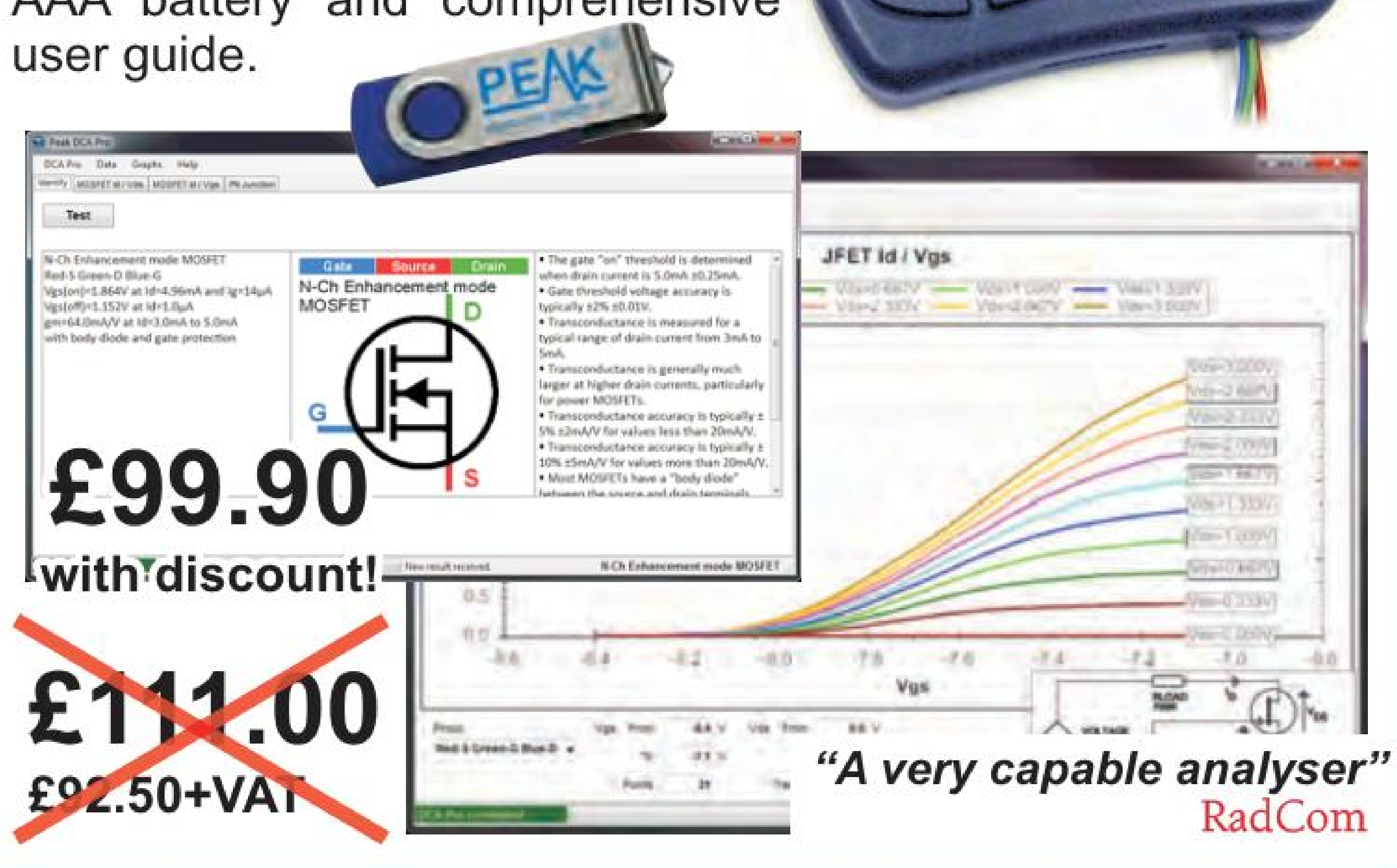
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